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The structure and function of the abdominal muscles during pregnancy and the immediate post-birth period

W. L. Gilleard
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**THE STRUCTURE AND FUNCTION OF THE ABDOMINAL
MUSCLES DURING PREGNANCY AND THE IMMEDIATE
POST-BIRTH PERIOD**

A thesis submitted in partial fulfilment of the
requirements for the award of the degree

MASTER OF SCIENCE (HONOURS)

from



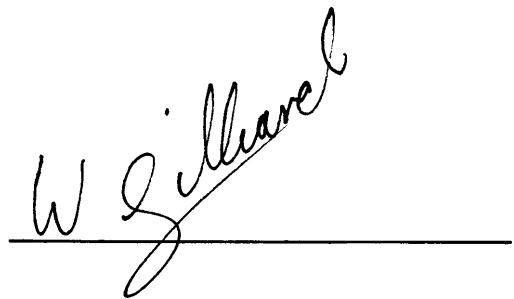
UNIVERSITY OF WOLLONGONG

by

W.L. GILLEARD, B. App. Sc.

DEPARTMENT OF HUMAN MOVEMENT SCIENCE, 1992

The work presented in this thesis is the original work of the author except as acknowledged in the text. I hereby declare that I have not submitted this material either in whole or in part for a degree at this or any other institution.

A handwritten signature in cursive script, reading "W Gilleard", is written over a horizontal line.

Wendy Lynne Gilleard

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DEDICATION

This thesis is dedicated to my children Kym and Amy
and my husband Les.

ABSTRACT

This study attempted to determine structural and functional changes to the abdominal muscles during pregnancy and the immediate post-birth period.

Six primigravid subjects with a single foetus participated in nine test sessions, from 14 weeks gestation to eight weeks post-birth. Three-dimensional photography of abdominal skin markers was used to calculate the length, separation and angles of insertion of a representative abdominal muscle, Rectus Abdominis. Functional capabilities of the abdominal muscles were then rated by a muscle test and by assessing the level of EMG signal produced during selected abdominal exercises.

Significant ($p < 0.05$) increases were found in Rectus Abdominis length, separation and angles of insertion as pregnancy progressed with a significant ($p < 0.05$) reversal in Rectus Abdominis separation by four weeks post-birth. Post-birth, the distance between skin markers could not be assumed to be reflecting the true length of Rectus Abdominis. Therefore post-birth Rectus Abdominis length and angles of insertion were not calculated.

The functional ability of the abdominal muscles was also found to be altered. The muscle test revealed a decreased ability of the subjects to stabilise the pelvis as pregnancy progressed, which remained diminished at eight weeks post-birth. Integrated EMG (IEMG) results

indicated some alterations in muscle activation patterns with External Oblique IEMG decreasing significantly ($p < 0.05$) as pregnancy progressed but increasing post-birth. Investigation of abdominal muscle inter-relationships also revealed changes over the duration of the pregnancy. For all abdominal exercises, upper Rectus Abdominis relative IEMG increased while External Oblique and lower Rectus Abdominis relative IEMG decreased. Relative IEMG for all tested muscles returned to levels seen at week 18/26 gestation by week eight post-birth. Functional changes found in Rectus Abdominis and External and Internal Obliques paralleled in time the structural changes found in Rectus Abdominis.

Thus, in combination, the results of this study have shown that the gross structure of Rectus Abdominis altered, the ability to stabilise the pelvis decreased and abdominal muscle activation patterns and inter-relationships altered as pregnancy progressed. During the immediate post-birth period, separation of the Rectus Abdominis was shown to be resolving by week four post-birth and abdominal muscle inter-relationships had returned to early pregnancy levels by eight weeks post-birth. However, the ability to stabilise the pelvis remained low at eight weeks post-birth. This sustained decrement in the ability to stabilise the pelvis at eight weeks post-birth may reflect the poor resolution of abdominal muscle length increases due to pregnancy.

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PUBLICATIONS

Publications in International Journals

Brown J. M. M. and Gilleard W. L., (1991) Transition from Rapid to Slow Movement; The Development of Triphasic EMG Patterns. European Journal of Applied Physiology 63: p 381 - 386

Publications in Conference Proceedings

Gilleard W. L. and Brown J. M. M., (1991) Structural Changes to the Rectus Abdominis During Pregnancy and Immediate Post-Pregnancy. Proceedings of XIIIth International Congress on Biomechanics. Perth.

Gilleard W. L. and Brown J. M. M., (1991) A Muscle Test for Abdominal Muscles; Validation and Results During Pregnancy and Post-Birth. Annual Scientific Conference in Sports Medicine Abstracts: Bridging the Gap. Canberra.
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Gilleard W. L. and Brown J. M. M., (1991) The Structure and Function of Abdominal Muscles during Pregnancy: Birth: Issues for the 1990's, Conference handbook. Melbourne.

Gilleard W. L. and Brown J. M. M., (1989) The Evolution of Triphasic EMG Patterns. Proceedings of the Seventh Biennial Conference of Cumberland College of Health Sciences: Motor Disturbances Mechanisms and Implications for Therapy. Sydney.

LIST OF ABBREVIATIONS

ANOVA.....analysis of variance

DLT.....Direct Linear Transformation

EMG.....electromyographic waveform

IEMG.....integrated electromyographical waveform

MT.....Muscle Test

n-IEMG.....normalised integrated EMG

rel-IEMG.....relative integrated EMG

$$\text{rel-IEMG} = \text{IEMG } m_1 / (\text{IEMG } m_1 + \text{IEMG } m_2 + \text{IEMG } m_3)$$

where m= muscle

subMVIC.....submaximal voluntary isometric contraction

SD.....standard deviation

WASP.....Waveform Analysis System Package

CHAPTER 1:

INTRODUCTION

Many women today wish to continue, or even begin, abdominal exercise programmes during their pregnancies. In addition, mothers are often encouraged to resume abdominal exercises shortly after delivery (Dale & Mullinax, 1988). The intended aim of such exercise programmes is to minimise the deleterious effects of pregnancy and parturition on the musculoskeletal system, such as backache and poor posture (Blankfield, 1967). However, the risks and benefits of abdominal exercise during pregnancy and the immediate post-birth period remain largely unknown (Shrock et al., 1981). In addition, very little formal research into the function and efficiency of abdominal muscles performing abdominal exercises recommended by specialist exercise leaders has been attempted.

It is known that the gross musculoskeletal structure of the abdomen alters during pregnancy to accommodate the gravid uterus, with increases in midline abdominal length (Fast et al., 1990) and the width of the linea alba (Boissonnault & Kotarinos, 1988) by 38 weeks gestation. Therefore the position, and angles of insertion of the abdominal muscles may be altered relative to the non-pregnant abdomen.

Changes to the angle of insertion of a muscle influences the muscle's line of action (Warwick & Williams, 1973). If the line of action of a muscle is

altered it follows then that there may be changes in the muscle's functional capabilities. Anecdotally, abdominal muscles are described as being stretched and weakened as a result of the accommodation process (Blankfield, 1967; Shrock et al., 1981). Additionally, some compromising of the abdominal muscles functional roles during pregnancy and the immediate post-birth period have been reported. Booth et al. (1980) at 38 weeks gestation using an EMG technique, found that abdominal muscles were utilised at amplitudes atypical of non-pregnant subjects. Spence (1978), found a trend towards increased abdominal muscle weakness in postpartum women. However, there is currently a paucity of information on the effect of known musculoskeletal adaptations during pregnancy on specific abdominal muscle gross structural changes. The effect on abdominal muscle function, due to gross structural changes caused by pregnancy, also remains largely unknown (Boissonnault & Kotarinos, 1988).

The objectives of the present study were to examine the structural and functional changes in the abdominal muscles during pregnancy and the immediate post-birth period utilising electromyography, three dimensional photography, and a simple muscle test. Specifically, the aims of the study were to investigate during pregnancy and the immediate post-birth period: -

a) Gross structural changes to a representative abdominal muscle, the Rectus Abdominis. The structural parameters investigated included muscle length, angles of insertion, and the width of the linea alba. The gross structure of Internal and External Oblique, and Transversus Abdominis were not studied due to difficulties in accurately modeling their structure.

b) The functional ability of the abdominal muscles to stabilise the anterior pelvis.

c) The functional capabilities of the abdominal muscles to move the trunk during certain abdominal exercises.

CHAPTER 2:

LITERATURE REVIEW

Part A. STRUCTURE OF THE ABDOMINAL MUSCLES IN PREGNANT AND NON-PREGNANT SUBJECTS

It has long been recognised that pregnancy is not considered an "illness" for the average female and so a normal healthy lifestyle for the pregnant women is advocated by todays obstetricians. However, pregnancy causes musculoskeletal adaptations, and the principles of kinesiological science tell us that the action and work a muscle can perform is dependent on its shape and structure. Therefore the anatomical changes to the muscle and connective tissue of the anterior abdominal wall caused by pregnancy may affect the functional capabilities of the abdominal muscles.

The Gross Structure of Abdominal Muscles

The musculature of the anterior abdominal wall includes four paired large flat muscles covering the antero-lateral lower trunk, together with a smaller triangular muscle pair located medially. They are the Rectus Abdominis, Internal and External Oblique, Transversus Abdominis, and Pyramidalis (Warwick & Williams, 1973).

Muscle Attachments and Fibre Orientation

The classical anatomical description (Kendall & McCreary, 1983; Romanes, 1964; Warwick & Williams, 1973) holds that there are two pairs of muscles whose fibres are orientated diagonally, the Internal and External Obliques. The External Oblique muscle has boney attachments on the external surfaces of the lower eight ribs and the anterior half of the iliac crest. The Internal Oblique muscle attaches to the lateral half of the inguinal ligament, the anterior two thirds of the iliac crest, the thoracolumbar fascia and the inferior borders of the lower four ribs. The fibres of the Obliques run medially, the External Oblique fibres are directed inferio-medial whilst the Internal Oblique fibres are directed superio-medial. The Transversus Abdominis forms the innermost layer. It arises from the lateral third of the inguinal ligament and the anterior two-thirds of the iliac crest, the thoracolumbar fascia and the inner surfaces of the lower six ribs and its fibres travel transversely. Muscle fibres from External and Internal Oblique, and Transversus Abdominis are inserted into broad aponeuroses and the lower border of the External Oblique aponeurosis is folded upon itself to form the inguinal ligament between the anterior superior iliac spine and the pubic tubercle. Located on either side of the anterior abdominal wall midline, the Rectus

Abdominis is a vertically orientated parallel fibred muscle which attaches superiorly to the costal cartilages of ribs five, six and seven, and inferiorly to the pubic crest and the symphysis pubis. The muscle has three tendinous intersections, the first is usually found at the level of umbilicus, another opposite the free end of the xiphoid process and the third midway between the first two. The Pyramidalis muscle is found anterior to the lower Rectus Abdominis, arising from the anterior pubis and pubic symphysis and inserting on the linea alba midway between the umbilicus and the pubis (Kendall & McCreary, 1983; Romanes, 1964; Warwick & Williams, 1973).

The Rectus Sheath

The aponeuroses of External and Internal Oblique, and Transversus Abdominis form the rectus sheath, within which lies the Rectus Abdominis and Pyramidalis muscles. The surface feature indicating the lateral edge of the Rectus Abdominis is known as the linea semilunaris. The composition of the rectus sheath has been previously investigated by Monkhouse and Khalique (1986). Above the arcuate line the aponeurosis of the Internal Oblique typically splits to enclose the Rectus Abdominis, while the External Oblique muscle remained anterior and the aponeurosis of the Transversus Abdominis remained posterior to the Rectus Abdominis. Below the arcuate

line, all three aponeurotic structures passed in front of the Rectus Abdominis. The arcuate line varied in its location from close to the umbilicus to near the pubic bone and both sides were not symmetrical. The Rectus Abdominis was separated from its pair by a connective tissue structure, the linea alba, where the aponeuroses of External and Internal Oblique, and Transversus Abdominis meet in the abdominal midline. Poirier (1912), described the linea alba as a two to three millimetre thick tendinous raphe extending 30-40 cm (mean 33cm) from the sternum to the pubis. It is a lattice of tendinous fibres, composed of two distinct parts. The upper part is six to eight millimetres wide at the sternum, 15 to 25 mm wide at the umbilicus and extends one to three centimetres below the umbilicus. The lower 13 cm section is a linear raphe, slightly wider at its attachment to the pubis.

Innervation of the Abdominal Muscles

The nerve supply of the anterior abdominal wall is from the lower six intercostal nerves and the first lumbar nerve. The intercostal nerves, when they reach the end of their intercostal spaces, pass behind the costal cartilages and enter the abdominal wall. The Lateral Cutaneous branches supply the External Oblique while the

main trunks of the intercostal nerves supply the Internal Oblique, Transversus Abdominis, and the Rectus Abdominis (Miyachi, 1985). There is some contention regarding the innervation patterns of the abdominal wall. Duchateau et al. (1988), describe the Rectus Abdominis as being segmentally innervated by the lower six intercostal nerves which enter the muscle on the deep surface in the middle. However, Monkhouse and Khalique (1986), supporting the findings of Davies, Gladstone and Stibbe (1931), found a plexiform arrangement of the intercostal nerves (particularly T9-T11) deep to the Internal Oblique prior to reaching the Rectus Abdominis as well as an overlap in the muscle itself. Therefore non-overlapping segmental innervation of the Rectus Abdominis cannot be assumed. Monkhouse and Khalique (1986), because of the overlap in innervation, also questioned whether tendinous intersections may represent the somatic derivations of the Rectus Abdominis.

Biomechanics of Abdominal Wall Tissue

The biomechanical properties of tissues from the abdominal wall are as follows. The maximum tensile strength of adult human Rectus Abdominis immediately after death is 38 g/mm^2 for the 10 to 19 age group and decreases to 32 g/mm^2 for the 20 to 39 years age group

(Yamanda, 1970). For the 10 to 29 age group the maximum elongation, just after death, is 107%, and there is no difference in values between males and females (Yamanda, 1970). Aponeurotic tissue from rabbit Rectus Abdominis sheath at 48 hours post-mortem, has a maximum expansive strength of $3.9 \pm 0.18 \text{ kg/cm}^2$, and a maximum strength per unit thickness of $43 \text{ kg/cm}^2 / \text{mm}$ (Yamanda, 1970). There is a paucity of data on human Rectus Sheath aponeurotic tissue, however rabbit data may be a good approximation in the author's view, as human skeletal muscle and fascia has maximum tensile strength and maximum expansive strength per unit thickness approximately equal to that of rabbits (Yamanda, 1970). Elbaz and Flageul (1979) suggests the anterior and posterior walls of the Rectus Sheath are elastic in the vertical direction and inelastic in the transverse direction, as a result of the interlacement of the aponeurotic fibres that compose it.

Structure of the Abdominal Muscle During Pregnancy

The musculoskeletal system, especially in the region of the trunk, is noticeably affected by pregnancy (Danforth, 1967). During pregnancy the weight of the uterus and its contents increases to approximately 6.5 kilograms at term (Boissonnault & Kotarinos, 1988). As the abdomen enlarges, the centre of gravity is moved

forward such that by the eighth month, the pregnant woman must adjust her posture in order to keep balance (Danforth, 1967). In addition, between the fourth and ninth months of pregnancy, there is an increase in thoracic kyphosis and lumbar lordosis (Bullock et al., 1987).

Separation of the Rectus Abdominis Pair (the Recti)

Pregnancy induced hormonal changes are thought to allow the pubic symphysis, sacroiliac and lumbar joints to be more mobile (Grieve, 1976; MacLennan, 1983; Rundgren, 1974). The hormone relaxin is also believed to have an effect on fibrous connective tissue, which allows the abdominal wall fascia to loosen (Boissonnault & Kotarinos, 1988; Danforth, 1967). This, coupled with the mechanical stress of an enlarging uterus may cause the Recti to separate (Boissonnault & Kotarinos, 1988; Noble, 1982). The effect of Recti separation on the function of abdominal muscles has not been previously investigated (Boissonnault & Kotarinos, 1988). Anecdotally, Noble (1982), suggests Recti separation is significant functionally, when greater than two centimetres, although Elbaz and Flageul (1979), prefer a greater than four centimetres criterion. Boissonnault and Kotarinos (1988), suggest any change in the orientation of the Recti may affect the ability of the abdominal muscle to function

normally. The effect of Recti separation and the point at which it becomes significant warrants further research.

The incidence of Recti separation among women in their childbearing year was investigated by Boissonnault and Blaschak (1988). Recti separation was classified using Noble's criteria (Noble, 1982) of any separation greater than two centimetres. Recti separation was observed 4.5 cm above and below umbilicus and at umbilicus, while the incidence increased as the pregnancy progressed. The most common position for Recti separation was at umbilicus (Boissonnault & Blaschak, 1988). Among postpartum women, research has shown 50% to 60% have Recti separation greater than two centimetres (Boissonnault & Blaschak, 1988; Bursch 1987; Spence, 1978).

Thoracic and Abdominal Morphology

The growing foetus is also a dynamic influence on the shape of the thorax and the abdomen. Considering the thorax first, the anterior and transverse diameters are increased to compensate for a reduction in the vertical diameter as the foetus increases in size (Artal et al., 1986; Gilroy et al., 1988; Goodlin & Buckley, 1984). Gilroy et al. (1988), found at the third intercostal space a mean thoracic cage circumference of 89 cm in the third trimester of pregnancy as against a mean

circumference of 84 cm at one month post-birth. Goodlin and Buckley (1984) state the effective maternal vertical diameter of the chest is decreased by approximately four centimetres, with a corresponding increase in transverse and antero-posterior diameters of up to ten centimetres, although these figures are unreferenced. The resultant increase in the inferior thoracic aperture diameter alters the position of the ribs relative to the pelvis. Thus the positions of the thoracic origins of the abdominal muscles relative to the pelvic and aponeurotic attachments is altered. Secondly, the obviously increasing anterior and lateral dimensions of the abdomen during pregnancy will increase the distance between the attachment points. Fast et al. (1990), found a significant increase for mean midline abdominal length from 31.85 ± 2.789 cm in nonpregnant women to 43 ± 4.031 cm at 38 weeks pregnancy. Polden (1985), anecdotally reports an increase in the distance between the xiphoid process and the pubis, from 30 cm to 50 cm during pregnancy. There is a void in the literature with regard to quantitative measurements of the Recti separation width and the angle of insertions of the abdominal muscle at both the superior and inferior attachment, during pregnancy.

In summary, the anterior abdominal wall includes four paired large flat muscles attached superiorly to the inferior thoracic cage, and inferiorly to the pelvic girdle. The anterior abdominal wall midline is composed of connective tissue, the linea alba. The attachment points of the abdominal muscles are not altered by pregnancy but the position of the attachment points and the shape of the muscles is altered to accommodate an enlarging mass, the foetus, beneath the abdominal muscles. Since the weight supported by the abdominal muscles is also increased, the abdominal muscles are subject to increased mechanical stress. This may change the angles of insertion in the sagittal plane and the muscle length. Also the mid-abdominal position of the Rectus Abdominis is moved laterally which may change the angle of insertion in the coronal plane. Further research to establish the gross structural changes to the abdominal muscles during pregnancy is warranted.

As discussed above, the dimensions of a pregnant female's abdomen alter as the pregnancy progresses. The abdomen increases in size anteriorly and laterally, and the thoracic cage is elevated. The abdominal muscles' length and angles of insertion may therefore be altered. To quantify these gross structural changes in size and shape, a three-dimensional model may be utilised.

Three-dimensional photography, using the Direct Linear Transformation (DLT) Method developed by Abdel-Aziz & Karara (1971), gives the three dimensional position in space of any point using two non-parallel non-metric cameras. The DLT method has been used for many applications of close range photogrammetry where three dimensional analysis is needed, including historical research (Ogleby, 1975), geology (Brandow et al., 1975), industry (Karara, 1975) and biomechanics (Alem et al., 1978; Shapiro, 1979).

The DLT method is based on the establishment of a relationship between a point's location in space and the film image coordinates. This relationship is defined in mathematical parameters calculated from data relating to object or 'control' points (known points located on a reference structure). DLT parameters contain implicit information relating to camera orientations, lens and

film distortion (Shapiro, 1978). A minimum of six control points are needed to determine the DLT parameters, but up to 20 control points will improve reliability (Karara & Abdel-Aziz, 1974; Shapiro, 1978). Twelve points however, will give acceptable results (Shapiro, 1978). The points must be located throughout the area in which the experimental objects will be filmed (Shapiro, 1978; Wood & Marshall, 1986). Karara and Abdel-Aziz, (1974), recommended the points be placed throughout the depth of field. It is critical to the calculations that stereo images of the points are gained. Therefore all points must be seen by both cameras (Shapiro, 1978; Shapiro, 1981).

The camera position used in the DLT method including the ratio of the distance from the object to the line between the two cameras, to the distance between the cameras, and the angle of convergence between the camera axes has been the subject of several investigations (Abdel-Aziz & Karara, 1974; Marzan, 1975; Shapiro, 1978; Wood & Marshall, 1986). Recent research has established that the DLT method may be used under a wide range of camera configurations with high reliability (Wood & Marshall, 1986).

Marzan and Karara, (1975), have established a method, as follows, for the analysis of static photographs. The reference structure containing markers

of known points (control points) is photographed by two cameras arbitrarily placed. The structure is then removed and the subject with desired markers (subject labels) is photographed in the same object space with the same camera set up. The digitised control points are then used to calculate the DLT parameters. The DLT parameters may be cross-checked by using the calculated parameters to predict position of the known control points. The DLT parameters are then used to calculate the three dimensional position in space of the experimental labels (Marzan & Karara, 1975).

The mathematical model on which the DLT parameters are based has also been investigated. Karara and Abdel-Aziz, (1974), have investigated six mathematical models. These models accounted for various sources of inaccuracies (up to 22 unknowns). The model they recommended for use in image-refinement for non-metric photography accounted for the linear components of lens distortion and film deformation, and the symmetrical lens distortion. Wood and Marshall, (1986) found if seven control points were used with a camera lens of good quality, the eleven-parameter model was acceptable. Recent investigators have used commercially available 35 mm SLR cameras and have achieved acceptable results (Ogleby, 1985; Wood & Marshall, 1986).

The accuracies of the DLT method are within those acceptable for traditional two dimensional techniques (Alem et al., 1978; Karara & Abdel-Aziz, 1974; Marzan & Karara, 1975; Shapiro, 1978). Studies have reported errors ranging from 5mm to 0.07mm (Alem et al., 1978; Marzan & Karara, 1975; Shapiro, 1978).

In summary, for the DLT method, the camera configuration is not critical while all points can be seen with both cameras and the control points are well distributed throughout the experimental space. The camera type is not critical, although the quality of the lens will determine the mathematical model used.

The DLT method provides a relatively easy procedure which establishes within reasonable accuracy limits, the three dimensional position in space for any point with a minimum of procedures for the subject. By marking the attachments and the outline of a muscle the three dimensional gross structure of the muscle may be determined by DLT. With such a technique, changes in the gross structure of the abdominal muscles may be recorded throughout the duration of pregnancy and the immediate post-birth period.

Part C. HORMONAL AND MECHANICAL INFLUENCES ON SKELETAL MUSCLE AND CONNECTIVE TISSUE DURING PREGNANCY

As discussed in Part A it is thought that there are both hormonal and mechanical influences on the anterior abdominal wall and pelvis during pregnancy. The anterior abdominal wall consists of muscle fibres surrounded by, and connected to, their attachment points by fibrous connective tissue. Therefore the effect of hormones, sustained stretch and increased workloads on muscle fibres and connective tissue must be considered.

Effect of Sustained Stretch on the Physiology of Skeletal Muscle Fibres

Muscle tissue is adaptable to alterations in its functional demands. Muscle tissue will atrophy if not used and a program of weight lifting will cause hypertrophy (Kreighbaum & Barthels, 1981; Stewart, 1972). In reference to muscle tissue, the term "use" refers to tension development and the common interpretation is active tension resulting from active muscle contraction. However, tension in a muscle can also be as a result of stretch, which is a passive tension imposed by an external force. As discussed earlier, abdominal muscles during pregnancy are subject to stretch from the

expanding uterus beneath, while the postural work load of the abdominal muscles is increased as the position of the centre of gravity changes due to the increased weight of the enlarging uterus and it's contents. Thus abdominal muscles during pregnancy are subjected to increases in both active and passive tension.

Addition of Sarcomeres

In mammals, sustained stretching of skeletal muscle, whether the limb is immobile or mobile, causes longitudinal growth due to the addition of sarcomeres in series along the length of the muscle fibres (Goldspink, 1977b; Goldspink et al., 1974; Tarbary et al., 1972; Williams & Goldspink, 1971; 1973; 1978; Williams et al., 1986). It has been shown that the new sarcomeres are added to the ends of existing myofibrils (Williams & Goldspink, 1971) and when the sustained stretch is removed the additional sarcomeres are lost (Goldspink et al., 1974; Williams & Goldspink, 1973). The increase in sarcomere number in response to the sustained stretch stimulus is a myogenic response within each fibre as it is not affected by denervation (Goldspink et al., 1974). In addition, when sustained stretch is removed, the return of normal muscle activity does not maintain the increased muscle length (Goldspink 1977b).

The increase in sarcomere number is the muscle's response to a reduction in its tension producing capabilities. The force a muscle can develop depends upon the degree of overlap of the thick and thin myofilaments (Gordon et al., 1966). The optimal sarcomere length is where the amount of overlap allows maximal interaction between the myosin cross bridges and actin filaments (Gordon et al., 1966). When a muscle is stretched beyond the optimal length the mechanical output is diminished, due to reduced overlap and therefore reduced interaction between the myofilaments (Gordon et al., 1966; Podolsky & Schoenberg, 1983). Under conditions of sustained stretch, skeletal muscle in response to the decrease in mechanical output, will add sarcomeres to regain the maximal functional interaction between the myofilaments (Williams & Goldspink, 1978).

Synthesis of Muscle Protein

Sustained stretching of a muscle also alters the synthesis of muscle protein. Several authors have reported increased rates of protein synthesis in skeletal muscle when it is stretched (Goldspink, 1977a; 1977b; 1978; Lougha et al., 1986). Protein degradation is also increased but the synthesis of protein is predominant (Goldspink 1978, Goldspink 1983, Lougha et al., 1986). Therefore there is an accumulation of muscle mass. The

increase in mass will include the formation of extra sarcomeres.

Increases in protein synthesis were seen in the rat after twelve hours of sustained stretch (Goldspink, 1977a; 1978). Increases in sarcomere number have been reported after one week of sustained stretch in the mouse soleus (Williams & Goldspink, 1973) and after four days of sustained stretch in the rabbit (Williams et al., 1986). Therefore the response to stretch in terms of sarcomere number adaptation and protein synthesis of skeletal muscle, is rapid.

Hypertrophy

Hypertrophy of muscles has been reported in response to sustained stretch (Alway et al., 1989; Holly et al., 1980; Lalatta Costerbosa et al., 1987; 1988; Martin, 1979; Sola et al., 1973). As with the increase in length in response to sustained stretch, the increase in the cross-sectional area is seen with or without denervation although the response is more rapid with an intact nerve supply (Sola et al., 1973). Sustained stretch is also reported to reduce the atrophy effects of reduced movement and force in both postural and phasic muscles of a rat's hindlimbs (Lougha et al., 1986).

The increase in the diameter of the muscle fibres is thought to be caused by an increase in the number of

myofibrils, along with an increase in the sarcoplasmic reticulum and the transverse tubular system (Goldspink, 1983). Goldspink, (1970) showed the myofibrils proliferated by splitting longitudinally. An increase in muscle fibre numbers has been reported by Sola et al. (1973), and more recently by Alway et al. (1989), in response to sustained stretch of skeletal muscles in chickens and Japanese quail. Holly et al. (1980) disputed the results of Sola et al. (1973). They felt that the new fibres seen by Sola et al. (1973) were pre-existing, intrafascicularly terminating fibres that grew in length into the plane of the sections used. These then stained like new fibres perhaps because similar proteins are synthesised in both embryonic fibres and in the ends of pre-existing fibres. The question of whether muscle fibers proliferate in response to stretch or whether it is an increase in fibre diameters only which causes overall muscle hypertrophy, remains unresolved.

Adaptation of Rectus Abdominis during Pregnancy: Results of Animal Studies

It can be seen from the above discussion that skeletal muscle is an adaptable tissue reflecting the functional demands which are placed on it. Pregnancy causes the abdominal muscles to be under a constantly increasing stretch, while supporting more weight and in

more constant use than in a non-pregnant female. The adaptive response to pregnancy of Rectus Abdominis in terms of fibre type as determined by histochemical responses, has been examined by Martin, (1979) in the rat and Lalatta Costerbosa et al. (1987 & 1988), in the guinea pig and rabbit. The normal fibre type composition of the Rectus Abdominis is predominantly Type II fibres, with Type IIB the most prevalent and very few Type IIC fibres (Lalatta Costerbosa et al., 1987; 1988; Martin, 1979). After 30 days of pregnancy, hypertrophy was seen in Type I fibres (Lalatta Costerbosa et al., 1988; Martin, 1979) and there was atrophy of Type IIB (Lalatta Costerbosa et al., 1988; Martin, 1979) but there was no change in fibre type proportions (Lalatta Costerbosa et al., 1987; 1988; Martin, 1979). After 70 days of stretch there was an increase in proportion of Type I fibres and a decrease in the Type IIA & IIB fibres (Lalatta Costerbosa et al., 1987; 1988). The hypertrophy and increase in proportion of Type I fibres, which are more resistant to fatigue, and the atrophy and decrease in proportion of type II fibres, was suggested as an indication of a change in the functional role of the Rectus Abdominis muscle due to the pregnancy to a role of more constant use and increased weight bearing (Lalatta Costerbosa et al., 1987).

Summary

Human abdominal muscles during pregnancy, as discussed earlier, are under sustained stretch and must support an increasing weight as the pregnancy progresses. When an animal muscle is subjected to sustained stretch, it grows in length and hypertrophies and so maintains its ability to produce adequate tension. Increased work in the form of active tension also causes an animal muscle to hypertrophy. Therefore in humans, a combination of increased passive and active tension may cause an increase in length and a hypertrophic response in the abdominal muscles of a pregnant female. The functional role of the abdominal muscles during pregnancy is also altered to more constant use and use with higher forces than are normally met. In animal studies a change in the histochemical response of skeletal muscle fibre is seen in response to this functional change therefore a similar response may be possible in humans.

The Effects of Hormones on Skeletal Muscles

The influence of hormones on human skeletal muscles was investigated in Japan in the mid 1950's (Kawakami, 1954; 1955; Takano, 1956). Reduced EMG activity was found in abdominal oblique muscles at rest and during bearing down for women during pregnancy although EMG activity increased 5 to 20 hours prior to the onset of labour (Takano, 1956). EMG activity for Rectus Abdominis and the oblique muscles was found to be altered in women in association with their menstrual cycle but not in males (Kawakami, 1954). Injections of progesterone were found to inhibit abdominal muscle electrical activity in menopausal women and castrated men but the inhibition effect of progesterone was reversed by estradiol and testosterone (Kawakami, 1954; 1955). The Bulbocavernosus muscle showed a similar reaction to progesterone, testosterone and estradiol (Kawakami, 1955). Oxytocin increased EMG activity in Bulbocavernosus muscle but reduced activity in the oblique abdominal muscles (Kawakami, 1955).

There appears to be a paucity of recent research on the effect of female hormones on abdominal muscles. Lalatta Costerbosa et al. (1988), cite literature indicating endocrine influences on animal skeletal muscle, and suggest hormones linked to pregnancy may be

involved in histochemical changes seen in pregnant rabbit Rectus Abdominis. However, no specific data on hormones associated with pregnancy was cited.

The Effect of Changes in Tension on the Physiology of Fibrous Connective Tissue

Tendons, ligaments and aponeuroses are composed of fibrous connective tissue containing the macromolecule collagen (Warwick & Williams, 1973). Their composition in general, is 20% cellular material (for example fibroblasts) and 80% extracellular material of which 70% is water and 30% is solid (Nordin & Frankel, 1989). The solid extracellular material is 75% to 99% collagen, aggregated into fibrils, with the remainder composed of elastin and ground substance (Nordin & Frankel, 1989).

In vivo, tendon and ligaments are responsive to factors such as loading from physical activity and immobilisation (Nordin & Frankel, 1989; Oakes & Parker, 1990; Tipton & Vailis, 1990). In response to exercise loading, adult animal tendons were found to be remodeled, with activated fibroblasts and the disaggregation of collagen bundles (Zamora & Marini, 1988). Exercise was also found to cause in adult animal tendons, an increase in collagen fibril size (Tipton & Vailis, 1990; Woo & Buckwalter, 1987), stiffness (Woo & Buckwalter, 1987),

ultimate strength (Tipton & Vailis, 1990; Woo et al., 1979; Woo & Buckwalter, 1987), and cross-sectional area (Woo et al., 1979). Woo et al. (1979) also found, after 12 months of exercise in one year old swine, a 40% decrease in the intermolecular reducible cross-links of collagen. Ligaments from adult animals, have also been found to increase in ultimate strength (Tipton et al., 1970; Tipton et al., 1967), fibre bundle diameters and collagen content (Tipton et al., 1970) in response to intermittent loading such as produced by exercise.

In contrast, immobilisation for six weeks causes a decrease in ultimate strength (Tipton et al., 1970; Tipton et al., 1967) and collagen fibre bundle diameters (Tipton et al., 1970) of animal ligaments. Recovery back to normal strength levels is slow, with 20 or more weeks needed to recover to full strength from six weeks of immobilisation (Tipton & Vailis, 1990).

During pregnancy, the type of loading on the abdominal muscle connective tissue is probably that of a sustained tension (Boissonnault & Kotarinos, 1988). In children, constant low loads elongate ligaments and tendons in the correction of clubfoot and idiopathic scoliosis (Nordin & Frankel, 1989). In adult animals, placing fibrous connective tissue under constant tension appears to have varying results. Dahnert et al. (1989) found sustained tension did not elongate rabbit

ligaments. However, Reynolds et al. (1988), when the suprahyoid complex of adult rhesus monkeys was placed under tension, found elongation occurred at the muscle-bone interface, muscle tendon interface and within the belly of anterior digastric. They concluded that adaptations to increased tension occurred first at the connective tissue attachments of the muscle. Adaptation of adult fibrous connective tissue under sustained stretch, such as that found in abdominal connective tissue during pregnancy, possibly may occur but the research is not conclusive.

In summary, animal studies show fibrous connective tissues in tendons and ligaments are adaptable. They respond to changes in loading by remodeling with activated fibroblasts changing collagen fibril size and fibre bundle diameters. Thus resulting in alteration of ultimate tensile strength, and possibly elongation when placed under constant stretch. The abdominal wall connective tissue may adapt to altered loading during pregnancy.

The Effect of Pregnancy on Fibrous Connective Tissue

a) Pregnancy Hormone Relaxin and Fibrous Connective Tissue

Relaxin is a hormone produced by the corpus luteum during pregnancy (MacLennan, 1983; MacLennan et al., 1986a; Quagliarello et al., 1979). Relaxin is present in the blood during human pregnancy from four to six weeks gestation, with the highest serum relaxin levels found in the first trimester (O'Byrne et al., 1978; MacLennan et al., 1986a; Quagliarello et al., 1979). Human relaxin serum concentration levels are lower during the second and third trimesters (O'Byrne et al., 1978; MacLennan et al., 1986a; Quagliarello et al., 1979), although this is possibly due to a dilution effect from plasma volume expansion (MacLennan, 1983). In animals, there is a rise in relaxin levels at parturition (MacLennan, 1983), although human studies have found differing results. For example, MacLennan et al. (1986a), found a rise in serum relaxin levels, although this was not supported by O'Byrne et al. (1978) and Quagliarello et al. (1979) who found no rise in relaxin at parturition. MacLennan et al. (1986a), suggest the rise in serum relaxin at parturition in humans, may be very brief and therefore not detected unless frequent sampling is used. Postnatally, serum

relaxin levels quickly drop almost to non-pregnant levels (MacLennan et al., 1986a; 1986b).

Receptor sites for the hormone relaxin have been identified for animals, in the uterus (McMurtry et al., 1978; Osheroff et al., 1990), mammary gland (McMurtry et al., 1978), pubic symphysis (McMurtry et al., 1978; McMurtry et al., 1980), cervix (McMurtry et al., 1978; Osheroff et al., 1990) and in the brain (Osheroff et al., 1990). In humans, relaxin receptor sites have been identified in dermal fibroblasts (McMurtry et al., 1980; Unemori & Amento, 1990).

Numerous physiological responses to relaxin have been noted (MacLennan, 1983). Oestrogen primed animals have shown increased flexibility in pubic ligaments (Chihal & Epsey, 1973). In humans, increased metacarpophalangeal joint laxity was found during pregnancy, increasing with second pregnancy (Calguneri et al., 1982), and increased pelvic joint pain was noted in women with higher than normal relaxin levels during pregnancy (MacLennan et al., 1986b). However, definite cause and effect relationship between relaxin and joint laxity in humans has not been established (MacLennan, 1986b). In early animal pregnancy, relaxin inhibits myometrium contractility, and increases uterine distensibility, although these responses have not been adequately studied in the human (MacLennan, 1983). In

humans, direct application of porcine relaxin to the cervix of near term women causes cervical softening, shortening and opening (MacLennan et al., 1980). Relaxin has also been found to stimulate human sperm motility in suboptimal motility samples, and increase sperm penetration into oocytes (Weiss, 1989).

Additional findings have shown that relaxin appears to influence collagen metabolism in target tissues (MacLennan, 1983). Relaxin, in vitro, causes increased growth in fibroblast numbers (McMurtry et al., 1980) and significant increases in collagen matrix turnover at human pregnancy sera relaxin levels (Unemori & Amento, 1990). MacLennan, (1983), suggests a possible mechanism of the action of relaxin in target tissues is that the connective tissue is remodeled by, active fibroblasts producing new collagen, an activated collagenolytic system causing increased breakdown, and alteration of the ground substance, with the net effect allowing increased extensibility and remodeling. However, this evidence is derived not from human studies but from animal studies.

b) Fibrous Connective Tissue Biomechanical Properties During Pregnancy

The biomechanical properties of tissues outside the reproductive tract was examined in rats by Rundgren (1974). During pregnancy and immediate postpartum (up to

7 - 9 days), for the pubic symphysis, there was a larger deformation at lower loads and decreased elastic stiffness in comparison to non-pregnant controls. Later postpartum (10 days after birth), the results were similar to nonpregnant values (Rundgren, 1974).

Biomechanically there was no change to the posterior cruciate ligament during pregnancy, however postpartum the elastic stiffness and the maximum load values reduced for first three days, then increased after first week to higher than non-pregnant values. Later postpartum, the values returned to non pregnant levels (Rundgren, 1974). The Peroneus Digiti Quinti muscle tendon showed reduced maximum stress values at end of gestation, and for the first week after parturition. The maximum stress values then returned to non-pregnant values. The amount of collagen in the muscle tendon, increased with pregnancy and remained high postpartum (Rundgren, 1974). In skin, maximum stress values increased during the first half of gestation, then returned to nonpregnant levels. The amount of collagen in skin during pregnancy is no different to non-pregnant amounts. The biomechanical property changes in tissues outside the reproductive tract found during pregnancy and postpartum are thought to be a result of side effects of processes used to morphologically and functionally alter the reproductive tract (Rundgren, 1974).

In summary, the hormone relaxin is found in humans during pregnancy and appears to act, in animal connective tissue, by remodeling through alteration of collagen metabolism and the ground substance. Relaxin receptor sites have been identified in the reproductive tract, mammary glands, pubic symphysis and the brain for animals, and in humans, in dermal fibroblasts. Physiological responses to relaxin have been found in animal pubic ligaments and myometrium, human cervix, sperm, and possibly ligaments, and altered biomechanical properties in pregnant and postpartum rat connective tissue outside the reproductive tract have been demonstrated. The effect of relaxin does not appear to be localised to the reproductive tract connective tissue and possibly may act on connective tissue such as the linea alba (Boissonnault & Kotarinos, 1988), however, the full role of relaxin in humans is unknown.

Summary

Animal studies indicate that skeletal muscle and fibrous connective tissue may be adaptable to conditions of sustained stretch and increased workload similar to those found in the human abdominal wall during pregnancy. There appears to be a paucity of research using adult human skeletal muscle and fibrous connective tissue under

these conditions. Early research using human skeletal muscle, indicates there may be altered electromyographical output in the presence of female hormones, however this has not been ratified by recent research. Human and animal fibrous connective tissue may be remodeled and more flexible under the influence of the hormone relaxin, however research on human fibrous connective tissue outside the reproductive tract is limited.

Part D. THE FUNCTIONS OF THE ABDOMINAL MUSCLES

Muscle activity is involved in many physical functions of the body including movement (Guyton, 1985). The effectiveness of a skeletal muscle depends on the torque produced by that muscle and in turn the torque production of a muscle is dependent on the tension it can produce and the length of the moment arm (Kreighbaum & Barthels, 1985). As previously discussed, during pregnancy there are possible gross structural changes to the abdominal muscles. These may affect the non-pregnant functional capabilities of those muscles.

The Function of Normal Abdominal Muscle

The abdominal muscles form the anterio-lateral abdominal wall which covers the abdominal and pelvic contents and creates a muscular link between the thoracic cage and the pelvis. In the erect posture, the abdominal muscles of some individuals show constant tonic activity and are thought to keep the abdominal viscera in place by opposing the effect of gravity on them and the anterior pelvis (De Troyer, 1983; Floyd & Silver, 1950; Hoit et al., 1988; Strohl et al., 1981). Although low back pain, lumbar lordosis and pelvic alignment have not been found

to be related to abdominal muscle functional ability (Nachemson & Lindh, 1969; Walker et al., 1987).

Contraction of the abdominal muscles, and in particular the Internal and External Obliques when the thorax and pelvis are fixed, will cause the abdomen to be compressed which increases intra-abdominal pressure. This action aids activities such as forced expiration, coughing, laughing, urination, vomiting and defaecation (Floyd & Silver, 1950; Warwick & Williams, 1973; Hoit et al., 1988; Strohl et al., 1981). When trunk flexion is included in compressive movements, the Rectus Abdominis is active (De Sousa & Furlani, 1974; Floyd & Silver, 1950).

All of the abdominal muscles acting together will flex the trunk, with the Recti being particularly active when a resistance has to be overcome (De Sousa & Furlani, 1974; Floyd & Silver, 1950). Lateral flexion of the trunk is achieved predominantly by the use of the Obliques ipsilaterally with a small contribution from the ipsilateral Rectus Abdominis (Zetterberg et al., 1987). The External Oblique of one side and the Internal Oblique of the other side acting together will rotate the trunk to the same side as the Internal Oblique (Goldman et al., 1987; Warwick & Williams, 1973; Pope et al., 1987). De Sousa and Furlani (1974), concluded that the Rectus

Abdominis was not involved in rotation of the trunk in the erect posture.

The pyramidalis is a tensor of the linea alba (Warwick & Williams, 1973) although it is often absent (Monkhouse & Kalique, 1986; Romanes, 1964).

The Functional Role of Abdominal Muscle during Pregnancy

Increased muscle length and altered angle of insertion may affect the functional capabilities of the abdominal muscles during pregnancy and the immediate post-birth period (Boissonnault & Kotarinos, 1988). The functional roles of abdominal muscles during pregnancy are assumed to be similar to the nonpregnant state, although there is a paucity of information on abdominal muscle function during pregnancy (Boissonnault & Kotarinos, 1988). The abdominal muscles in the pregnant female are also used for the expulsive stage of labour (Danforth, 1967; Desanto, 1983). The task of performing the functional role of the abdominal muscles may be more difficult during pregnancy due to the increased weight of the abdominal contents and the anatomical changes outlined above. Thus the ability of the abdominal muscles to function as they do in the nonpregnant state, particularly in the third trimester, is questionable.

Fast et al. (1990) found a reduced ability to perform situps in women at 38 weeks gestation. Booth et al. (1980) also investigated abdominal muscles and exercise during pregnancy and postpartum. An increase in EMG output of the abdominal muscles during the exercises was noted as pregnancy progressed. A functional change in the abdominal muscles was indicated by the recruitment of abdominal muscles in movements they did not normally participate in (Booth et al., 1980). Further investigation as to the development of functional changes in the abdominal muscles during pregnancy and immediate postpartum is warranted.

Summary

The functional roles of the abdominal muscles include, support of the abdominal contents, stabilisation of the pelvis, increase intra-abdominal pressure to aid in coughing, laughing, forced expiration and to perform flexion, rotation and lateral flexion trunk movements. During pregnancy the functional roles of the abdominal muscles are thought to be similar with the addition of expulsion of the foetus during the second stage of labour. However the ability to perform these functional roles is questionable due to gross structural changes. Research indicates there is some change in the function

of abdominal muscles during pregnancy which may compromise the functional roles at this time, and further research is warranted.

Part E. SKELETAL MUSCLE FORCE PRODUCTION AND APPLICATION

The amount of tension a muscle produces when it contracts, and the application of that tension, will determine the functional capability of the muscle. The tension a muscle can produce is affected by such things as the number of muscle fibres recruited, the fibre type, the anatomic fibre arrangement and fibre size, the length of the muscle at the time of stimulation and during the contraction, and the speed of contraction (Gowitzke & Milnar, 1988; Kreighbaum & Barthels, 1985). The angle and point of muscle attachment to the bone, determines how the tension produced by the muscle will be applied (Gowitzke & Milnar, 1988; Kreighbaum & Barthels, 1985). During pregnancy the length and angle of attachment of the abdominal muscles may be altered. Therefore a review of the potential effect of these changes follows.

Skeletal Muscle Length Tension Relationship

The tension a muscle produces when it is stimulated to contract, is related to its length when it is activated (Crawford & James, 1980; Gowitzke & Milnar, 1988). Maximum tension production in parallel fibred muscles is found at lengths only slighter greater than rest length, whereas pennate muscles produce maximum

tension at slightly greater relative stretch (Gowitzke & Milnar, 1988). Generally the optimal muscle length (where greatest force is produced) is approximately 1.2 to 1.3 times the resting muscle length and less muscle tension is produced at greater or lesser lengths creating an active length-tension curve (Gowitzke & Milnar, 1988). When a muscle is passively stretched, the elastic components (connective tissue and sarcolemma) generate passive tension which if measured at different muscle lengths creates a passive tension curve (Crawford & James, 1980; Gowitzke & Milnar, 1988). The shape of the length-tension curve varies from muscle to muscle depending on the fibre arrangement (Crawford & James, 1980; Woittiez et al., 1983). Woittiez et al. (1984) using a model to predict the relationship between the structure of a muscle and its fibre function, found pennated muscles have narrow active and steep passive length-tension curves whereas parallel fibred muscles have wider active length-tension curves and less sloped passive curves. The change in muscle length necessary to produce a substantial reduction in muscle tension production is therefore greater for parallel fibred muscles than for pennate fibred muscles. The maximum tension produced by the pennate muscles was greater than the parallel fibred muscles. The model accounted for the distribution of muscle mass along the long axis of the

muscle and the variation of fibre length and angle along this axis but it assumed the active length-tension relationship of a muscle fibre was parabolic (Woittiez et al., 1984). A model which incorporated the asymmetry of the active length-tension curve was developed by Kaufman et al. (1989). The model predicts normalised muscle force as a function of muscle strain and the index of architecture. The index of architecture is the ratio of mean fibre length to the muscle belly length at muscle optimum length (Woittiez et al., 1983; 1984). For example, parallel fibred muscles such as Sartorius have an index of architecture of 1, whereas Semimembranosus and the more pennated Gastrocnemius Medialis have index of architectures 0.7 and 0.36 respectively (Woittiez et al., 1984).

Rectus Abdominis is a parallel fibred muscle. Due to the tendinous intersections, the total length of the fibres is less than the distance from origin to insertion and so its index of architecture would be less than one. From the discussion above however, it should be expected that the decrease in active tension production due to small increases in length would not be substantial.

The Influence of Angle of Attachment on Torque Production of Skeletal Muscle

Mechanically, if a force does not act directly through an axis of rotation it will have a turning effect (torque) on a body segment. The shortest distance between the line of action of the force, which is determined by the angle of attachment of the muscle, and the axis of rotation is the moment arm (ma). Given the relationship $\text{Torque} = \text{force} * \text{ma}$, the larger the moment arm the greater the torque produced by the force (Kreighbaum & Barthels, 1985).

The moment arm length for Rectus Abdominis *in vivo* for the non-pregnant female have been investigated by computer tomography (Nemeth & Ohlsen, 1986; Reid et al., 1985). Reid et al. (1985) calculated the ratio of Rectus Abdominis moment arm length to anteroposterior trunk depth. A mean moment arm ratio of 0.40 for females was found. Nemeth and Ohlsen, (1986) found the Rectus Abdominis moment arm length at the level of the lumbosacral joint was 80 ± 6 mm.

Theoretically, maximum torque will be produced with the muscle at a 90 degrees angle of pull where the moment arm is at maximum length, and angles of pull above and below 90 degrees will result in reduced torque (Kreighbaum & Barthels, 1985). In practice it has been found that strength (maximum force that can be exerted by a body segment) varies with the angle of pull but the relationship between strength and angle of pull varies

for different joints and the strength differences were not always significant (Campney & Wehr, 1965).

A theoretical model for the lower limb (Hoy et al., 1990), examining the effect of muscle, tendon and moment arm on the joint angle-torque relationship, found that the joint angle where a muscle develops peak isometric torque is affected by the moment arm, the optimal fibre length and the tendon slack length (length of tendon beyond which the tendon begins to develop elastic force). The joint angle where torque peaks is not necessarily the same as the joint angle where the muscle force peaks, or the joint angle where the moment arm peaks (Hoy et al., 1990).

Separation of the Rectus Abdominis in the midline and passing over the expanding uterus, may alter the angle at which the muscle attaches therefore altering the line of action of the muscle. The torque produced would therefore be expected to alter but the amount of change in angle of pull that will effect the practical strength of the muscle is unknown. The effect of pregnancy on the tendons and intertendinous connections of Rectus Abdominis is unknown, but it is possible that the length of the muscle tendon may be increased as discussed earlier. This may affect the tendon slack length which may alter peak torque production.

Summary

In summary, the optimum muscle length for parallel fibred muscles such as Rectus Abdominis, is slightly greater than resting muscle length and the maximum tension produced is less than that of pennate fibred muscles. The parallel fibred muscle's active length-tension curve is wider and the slope of the passive length-tension curve is less than that for pennate fibred muscles.

The maximum torque produced by muscles varies with the angle of pull. The joint angle where a muscle develops peak torque is effected by the moment arm, the optimal fibre length and the tendon slack length. Peak torque production in Rectus Abdominis during pregnancy may be altered by changes in angle of pull, and the tendon slack length.

Part F.

ABDOMINAL MUSCLE EXERCISES

As stated earlier the abdominal muscles functions include flexion, lateral flexion and rotation of the trunk. Exercises designed to strengthen the abdominal muscles are based on these trunk movements performed against some resistance. In the supine position the resistance is the weight of the body as it is pulled downward by gravity.

Abdominal Muscle Exercises in Non-pregnant Subjects

Abdominal exercise programmes are effective in increasing muscle strength (Thomas & Ridder, 1989) and the appropriateness of many different abdominal exercises have been evaluated (Ekholm et al., 1979; Flint & Gudgell, 1965; Furlani & Bankoff, 1987; Gutin & Lipetz, 1971).

Pelvic Tilt Exercise

The pelvic tilt exercise involves the flattening of the lower back, the pelvis rotating up at the front and down in back, the abdomen pulling in and the unlocking of the knees (Shearer, 1981). The movement is performed by Rectus Abdominis (Flint & Gudgell, 1965; Kendall & McCreary, 1983) and the External Oblique (Kendall &

McCreary, 1983; Shearer, 1981). However it is possible to perform the movement while supine by contracting the hip extensors and pushing with the feet to "rock" the pelvis back into a posterior tilt (Kendall & McCreary, 1983). Care must be taken to ensure the subject is not using this method as the movement is no longer valid as an abdominal exercise.

Curl-up Exercise

One definition of the symmetrical curl-up exercise is a situp performed with a rounded back. The lower limbs are flexed. The subject, using her abdominal muscles (Kreighbaum & Barthels, 1985), raises her trunk, keeping the back curved and continues lifting until she is sitting upright. For the curl-up, the Rectus Abdominis use is graded as 'strong' by Flint (1965) over the first 45°, 50% of maximum isometric activity by Ekholm et al. (1979) and in the middle intensity scale by Gutin and Lipetz (1971). The oblique abdominal muscles were recorded as 60% of a maximum voluntary isometric contraction, for a curl-up (Ekholm et al., 1979). Hip flexors are also used during curl-ups. The Iliacus activity increases to a 'strong' grade over the first 45° of a curl-up, and continues 'strong' activity to 90° (Flint, 1965).

Diagonal Curl-up Exercise

The curl-up with a diagonal twist (where the shoulders are rotated) is a similar movement to a symmetrical curl-up but is designed to predominantly use the rotators of the trunk such as the Internal and External Obliques. The Rectus Abdominis response to the diagonal curl-up exercise was found to be moderate by Flint (1965). Ekholm et al. (1979), found the Obliques response was 90% of a maximum isometric contraction, and the Rectus Abdominis was 40%. There was 'trace' Iliacus activity for the first 45° of a curl-up with diagonal twist, and Iliacus activity rose to 'mild' for the last 45° (Flint, 1965).

Seated Tilt-back Exercise

During a seated tilt-back exercise, the sitting woman with her lower limbs flexed performs a posterior pelvic tilt and slowly leans backwards until she feels unstable, and then returns to the upright sit. The first part of the movement uses the abdominal muscles eccentrically. The Rectus Abdominis was found to have a 'mild' activity level during the first 45° of a seated tilt-back exercise and Iliacus had a 'moderate' grade activity (Flint, 1965). During the return to the upright

position, Flint (1965) graded the the Iliacus activity as 'strong' and the Rectus Abdominis as 'moderate to mild'.

Isometric Abdominal Exercise

Floyd and Silver (1950), found the Rectus Abdominis was dominant when the head was lifted in the supine position, but as the level of effort increased the External and Internal Obliques were recruited. Strohl et al. (1981) also found activity in Rectus Abdominis when flexing the head against a resistance. They did not find any activity in the External Obliques but there is no indication of the level of effort the subject was making. An isometric contraction of the Rectus Abdominis showed a middle range activity response in investigations by Flint & Gudgeon, (1965), and Gutin and Lipetz, (1971).

Raising Intra-abdominal Pressure

Contraction of the abdominal muscles when the pelvis and thoracic cage are fixed will cause the abdomen to be compressed (Warwick & Williams, 1973) thus raising the intra-abdominal pressure. An increased intra-abdominal pressure is used during coughing and forced expiration. During forced expiration and coughing, Floyd and Silver, (1950), found the External and Internal Obliques are used, with relatively little activity in the Rectus Abdominis. However De Sousa and Furlani, (1974), found

the Rectus Abdominis to be active during coughing and forced expiration.

Segmental Response of Rectus Abdominis

The Rectus Abdominis, because of the possible segmental innervation of the segments divided off by the tendinous intersections, is thought to be able to be active on a segmental basis (Stanhope, 1987). Authors typically divide the Rectus Abdominis into upper and lower segments with the umbilicus as the mid point (Ekholm, 1979; Flint 1965; Flint & Gudgeall, 1965; Furlani & Bankoff, 1987; Gutin & Lipetz, 1971; Girardin, 1973; Stanhope, 1987), although a middle segment was used by DeSousa & Furlani (1974). For the curl-up exercise, different levels of activity in the upper and lower Rectus Abdominis were seen by Girardin (1973) and, Gutin and Lipetz (1971), but similar levels were seen by Flint (1965) and Ekholm et al. (1979). Ekholm et al. (1979), and Flint (1965), found each segment's response to be moderate to a diagonal curl up exercise. During a curl down, Flint (1965) found the upper Rectus Abdominis initially showed more activity but in the last 45 degrees of the movement the two segments were equal in activity levels (strong). Differing segmental use has been demonstrated in isometric contractions of the Rectus

Abdominis (Gutin & Lipetz, 1971; Flint & Gudgeall, 1965) and for the pelvic tilt exercise (Flint & Gudgeall, 1965).

Further evidence for the segmental use of Rectus Abdominis was given by Stanhope (1987) when he demonstrated that only the upper segment shortened during a flexion task. However no segment was dominant during the exercises from subject to subject or even within trial to trial for each subject. Stanhope (1987) therefore concluded that the recruitment of the segments is based on the proprioceptive influences predominant at the time rather than some pre-designated segmental neuromuscular pattern. De Sousa and Furlani (1974) however, found that all segments of the Rectus Abdominis were usually active simultaneously and that partial use was very rare for forced expiration, flexion of the trunk (supine position), raising of the head and coughing.

Interpretation and direct comparison of results from different authors are difficult. Various author's results will differ if the exercise is done at different speeds, if there is slight variation in technique or age, or if the subject's sex and physique vary (Booth et al., 1980). Segmental use of the Rectus Abdominis was found by all authors using segmental recording setups, except one. Therefore the segmental use of Rectus Abdominis appears to be the dominant finding in the nonpregnant subject.

Abdominal Muscle Exercises for Pregnancy and Post-birth

Women are encouraged to exercise during pregnancy but it cannot be assumed that all abdominal exercises are safe (Boissonnault & Blaschak, 1988; Bursch, 1987; Gleeson & Pauls, 1988; Shearer, 1981; Shrock et al., 1981; Spence 1978). Musculoskeletal changes during pregnancy and immediate post-birth, as discussed earlier, may affect the performance of many movements. Balance and stability are affected by the shifting forward of the centre of gravity (Danforth, 1967). The influence of hormones induce a softening and relaxation of the pelvic girdle and lumbar joints in pregnancy and an increased range of movement in the sacroiliac joint (Grieve, 1976). Therefore care must be taken to ensure the joints are not injured while undertaking exercise. Adductor stretches which involve passively pressing, or bouncing the knees down may cause a subluxation of the pubic symphysis (DeSanto & Hassid, 1983; Shrock et al., 1981). Any exercise which increases the lumbar lordosis, such as full situps (lumbar hyperextension occurs prior to the execution of all situps (Ricci et al., 1981), double leg raises and "bridging" should be avoided (DeSanto & Hassid, 1983; Gleeson & Pauls, 1988; Shrock et al., 1981). Sudden or severe abdominal exercise may aggravate Recti separation (DeSanto & Hassid, 1983; Shearer, 1981;

Shrock et al., 1981), therefore all abdominal exercises should be done slowly.

Why Exercise Abdominal Muscles During Pregnancy ?

Strong abdominal muscles during pregnancy are advocated to, improve abdominal muscle performance during the second stage of labour (Danforth, 1967; DeSanto & Hassid, 1983), correct poor posture (Blankfield, 1967; Danforth, 1967; DeSanto & Hassid, 1983; George & Berk, 1981; Noble, 1982; Shearer, 1981), reduce backpain (Danforth, 1967; Gleeson & Pauls, 1981; Noble, 1982; Shearer, 1981; Shrock et al., 1981), ensure the return of a "prepregnant waistline" (Blankfield, 1967; Spence, 1978), and to prevent Recti separation (Blankfield, 1967). Post-birth, abdominal muscle exercise is encouraged to rehabilitate the effects of pregnancy (George & Berk, 1981; Polden, 1985). However, the benefits and risks of abdominal muscle exercise during pregnancy and immediate post-pregnancy are unknown (Shrock et al., 1981). Shrock et al. (1981), questions whether exercise does help to retain the waistline and asks if exercise may possibly exacerbate an existing Recti separation. The effect of Recti separation (a common feature), on the function of the abdominal muscles is also unknown (Boissonnault & Blaschak, 1988). Many

therapists indicate the need for formal research in abdominal exercise during pregnancy (Boissonnault & Blaschak, 1988; Bursch, 1987; Gleeson & Pauls, 1988; Shearer, 1981; Shrock et al., 1981; Spence, 1978).

Abdominal Exercises Preferred During Pregnancy and Immediate Post-pregnancy

Although women are encouraged to maintain their abdominal muscles during pregnancy, physical therapists are very cautious about the exercises they deem to be safe. During pregnancy, the most commonly recommended abdominal exercise is the pelvic tilt exercise (Blankfield, 1967; Danforth, 1967; DeSanto & Hassid, 1983; Gleeson & Pauls, 1988; Noble, 1982; Polden & Mantle, 1990; Shearer, 1981; Shrock et al., 1981; Simons, 1987; Spence, 1978). The pelvic tilt exercise could be performed in many different body positions such as supine with knees bent, standing, and on hands and knees (DeSanto & Hassid, 1983; Noble, 1982). The pelvic tilt is recommended to stabilise the pelvis before doing any exercise, to protect the lower back (DeSanto & Hassid, 1983). The pelvic tilt exercise can also be used to compensate for the movement forward of the centre of gravity while standing (Shrock et al., 1981). The seated tilt-back exercise was recommended by fewer authors

(Noble, 1982; Shrock et al., 1981). To primarily work the external oblique muscles the seated tilt-back can be done with the shoulders in a diagonal position (Shrock et al., 1981). However, there has been disagreement amongst authors with regard to the curl-up exercise and its efficacy. Shrock et al., (1981) stated that the curl-up exercise was too difficult for weak abdominal muscles. Noble (1982), however, recommended diagonal and straight curl-ups for women who commence abdominal exercises early in pregnancy, but recommended a modified curl-up if separation of the Recti was present.

The abdominal exercises suggested during pregnancy, are also recommended post-birth. The pelvic tilt exercise was again the most commonly recommended exercise (Noble, 1982; Polden & Mantle, 1990; Simons, 1987), while the seated tilt-back was also recommended (Noble, 1982; Polden & Mantle, 1990). Noble, (1982) recommended the curl-up, and diagonal curl-up exercise, although, a modified curl-up was suggested for weak abdominal muscles (Noble, 1982; Polden & Mantle, 1990; Simons, 1987).

The types of exercise activity participated in by women during pregnancy, are varied, and it appears that if women are familiar with the activity, they may continue it throughout their pregnancies (George & Berk, 1981). However, many activities, such as aerobic classes, may have to be tailored for the non-pregnant client.

Therefore, the pregnant subject participating in general exercise classes may be attempting to perform abdominal exercises, such as curl-ups, that are not necessarily recommended by all authors.

When Should Exercise Begin ?

If the subject is not already participating, as an ideal exercise for improving abdominal muscle strength should begin early in pregnancy (Blankfield, 1967; DeSanto & Hassid, 1983; Gleeson & Pauls, 1988). Later in pregnancy the abdominal muscles are under considerable tension (DeSanto & Hassid, 1983; Gleeson & Pauls, 1988) and the enlargement of the growing foetus will make performance of exercises difficult (Blankfield, 1967). Booth et al. (1980) noted that there was an increase in the number of "effective" exercises for pregnant women as compared to nonpregnant women. Therefore abdominal exercises were more difficult for the 38 week pregnant female. Commencing exercise early also allows time for slow, progressive increases in the amount of exercise done (DeSanto & Hassid, 1983), that is needed to reach a level where the muscle strength is adequate.

Assessment of Abdominal Exercise Performance During Pregnancy and Post-birth

Few authors have investigated abdominal exercises during pregnancy and immediate post-pregnancy (Booth et al., 1980; Fast et al., 1990; Spence, 1978). Fast et al. (1990), assessed abdominal muscle functional ability in pregnant women, mean gestation of 38 weeks, using a sit-up. The sit-up performance was accepted if the supine subject was able to lift her head, shoulders and upper torso off the plinth to at least 40° of trunk flexion. Fast et al. (1990) concluded there was a reduced ability to perform sit-ups at 38 weeks gestation. Spence, (1978) graded the six weeks post-birth performance of crook lying curl-ups with varying upper limb positions. The grades ranged from, less than 60%, for a curl-up with hands stretching forward, to 100% for a curl-up performed with hands clasped behind the neck. Spence (1980) concluded that pregnancy appears to reduce the strength of Rectus Abdominis although not significantly. Booth et al. (1980), assessed the electromyographical signal output when performing abdominal exercises, in non-pregnant subjects, at 38 weeks gestation, five days post-birth and six weeks post-birth. Booth et al. (1980) noted there were differences in the electromyographical output related to whether the test was conducted close

to, or remote from, the time of birth, however, there was no statement as to the ability of the subjects to completely perform the abdominal exercises used.

Summary

Abdominal exercises may be used to increase muscle strength and the use of abdominal muscles during exercises was discussed for the non-pregnant subject. The pregnant and immediate post-pregnant subject may have abdominal muscle gross structural changes and possibly reduced abdominal muscle function. The continued strength of the abdominal muscles is thought to be important to maintain good posture and prevent possible backpain during pregnancy and immediate post-birth. Throughout pregnancy the pelvic tilt and seated tilt-back exercises are recommended. The curl-up type exercises are recommended with caution. However, non-recommended exercises may be attempted in exercise activities not specialising in pregnant clients. There is a paucity of research on abdominal muscle function and the performance of abdominal exercises by women during pregnancy and immediate post-birth. The available data are limited and does not appear to examine possible changes in ability to completely perform the exercises as the pregnancy progresses and immediately post-pregnancy. Physical

therapists are divided as to even the benefits of abdominal exercise and tend to be conservative in their recommendations because of the unknown risks and conjectured benefits. Clearly research is needed to establish the functional changes in the abdominal muscles, and the ability of subjects to perform abdominal exercise during pregnancy and immediate post-pregnancy, in order to more fully understand the possible risks or benefits which may occur.

Electromyography (EMG) is a technique for detecting the electrical signal of contracting muscle. Since the electrical output of the muscle is the direct result of muscle activation it follows that the EMG signal may be related to the force the muscle is producing and therefore may be used to assess muscle function. The signal is affected by the anatomical and physiological properties of the muscle and the characteristics of the instrumentation used to detect and observe it.

The Basis of the EMG Signal

The Motor Unit

The basic functional unit of a skeletal muscle is the motor unit, consisting of one motor neuron and all the muscle fibres supplied by that neuron. An action-potential propagated along the motor neuron causes all innervated muscle fibers to contract (Crawford & James, 1980). Each motor unit has a territory, approximately one third of the cross-sectional area of the muscle, while the muscle fibres of each motor unit are scattered throughout each unit's territory with little or no tendency to grouping (Brandstater & Lambert, 1973). Characteristically the number of muscle fibres per

motor unit varies. In general, muscles controlling fine movement have the smallest number of muscle fibres per motor unit and large coarse acting muscles have larger numbers of fibres per motor unit, but also within each muscle there is a range of sizes (Basmajian & DeLuca, 1985).

Action Potentials

The motor neuron action potential induces the muscle fibre sarcolemma to depolarise. The accompanying movement of calcium ions generates an electromagnetic field near the fibres (Basmajian & DeLuca, 1985). An electrode located in this field will detect a voltage (with respect to ground) which moves in time, known as an action potential (DeLuca, 1979). The amplitude of the detected single action potential is affected by the fibre diameter size and the filtering properties of the electrode (Basmajian & DeLuca, 1965). The duration of the action potential is related to the conduction velocities of the nerve branch and the muscle fibre (Basmajian & DeLuca, 1985).

The EMG signal is affected by its passage through various tissues prior to its detection (Basmajian & DeLuca, 1985; Epstein & Foster, 1983; Moritani & Muro, 1987). Muscle has a non-homeogenic anatomical construction which causes a non-even current distribution

and this is compounded by the different electrical properties of muscle, skin and fat which cause inflections in the current field as the signal propagates through them (Basmajian & DeLuca, 1985). The impedance to the current flow is greater in a direction perpendicular to the muscle fibres and less in a direction parallel to the fibres making muscle tissue anisotropic (direction dependent) (Epstein & Foster, 1983). The impedance is less for lower frequencies than for higher and this creates a low pass filter whose bandwidth decreases as the distance travelled through tissue increases (Moritani & Muro, 1987). At higher frequencies, the signal amplitude will decline sharply near the surface of the muscle fibre and then gradually diminish as the electrode moves further away (Andreasson & Rosenfalck, 1978). Muscle and the adjacent tissues therefore may be considered as distance dependent filter (Basmajian & DeLuca, 1985).

Motor Unit Action Potential

Depolarizations of the individual muscle fibres overlap in time, therefore the resultant signal at the detection site is a combination of each fibre's action potential, the motor unit action potential (Basmajian & DeLuca, 1985). The shape and amplitude of the motor unit action potentials are dependent on the geometric

arrangement between the electrode and the muscle fibres as well as the other factors which affect individual action potentials (DeLuca, 1979).

To sustain a muscle contraction, the motor units must be repeatedly activated, with the resulting EMG signal affected by the number of active motor units (recruitment), cancellation due to superposition of motor unit action potentials, dependence between motor unit action potentials, and the factors which influence motor unit action potentials (Basmajian & DeLuca, 1985).

Therefore, the observed EMG waveform is the result of all the action potentials within the detection area. It is affected by the geometric arrangement between the electrodes and active fibres, and the filtering functions of the tissues and electrodes.

Detection, Amplification and Storage of EMG Signal

For EMG signals to be observed they must first be detected. The signal is then amplified and stored for later analysis.

Electrodes

One type of electrode used in EMG analysis is the surface electrode, which is gelled (electrolyte paste) and attached directly to the skin over the muscle of

interest. The electrode detection surface senses the current generated by the calcium ionic movement during muscle fibre depolarisation (Basmajian & DeLuca, 1985). The use of surface electrodes is recommended when the EMG signal is required from a large amount of the muscle, or when information required is contained in the onset timing of the signal and the signal magnitude (Basmajian et al., 1975; Basmajian & DeLuca, 1985). Surface electrodes are also recommended when palpation is impractical to study the simultaneous activity or interplay of activity in a large group of muscles (Basmajian et al., 1975; Basmajian & DeLuca, 1985). However electrode-electrolyte gel-skin interfaces, have impedances and act as a high pass filter whose voltage bandwidth is related to the area of the electrode detection surface (Basmajian & DeLuca, 1985).

A disadvantage of surface electrodes is that they can only be effectively used with superficial muscles, and crosstalk (signal from adjacent muscles) is also a problem with small muscles (Basmajian et al., 1975; Basmajian & DeLuca, 1985).

Skin Preparation

Surface electrode electrical contact is improved by the use of electrolyte paste or gel (Basmajian & DeLuca, 1985). Skin electrical impedance is lowered by removing

the dead surface layer of the skin and its protective oils. This is done by light abrasion at the site (Tam & Webster, 1977) and cleansing with alcohol. Skin impedance at the electrode site may also be lowered by scratching the skin lightly with a needle, which is less painful than abrading (Okamoto et al., 1987).

An electrical current, containing both an ac and dc component, may be generated at the electrode-electrolyte junction due to a lack of chemical equilibrium (Basmajian & DeLuca, 1985). This current may vary with temperature fluctuations, sweat accumulation, changes in electrolyte concentration of the paste or gel, relative movement of metal and skin and the amount of current flowing into the electrode (Boter et al., 1966). The dc component is removed by using paired electrodes in conjunction with a differential amplifier and the ac component is reduced by "providing a reversible chloride exchange interface with the metal of the electrode" as used in the silver-silver chloride electrodes (Basmajian & DeLuca, 1985).

Bipolar Electrode Arrangement

Surface electrodes may be used in pairs, known as a bipolar electrode configuration, which uses two detection surfaces over the muscle of interest and an earth electrode in an electrically unrelated environment (Basmajian & DeLuca, 1985). However, bipolar surface

electrodes effectively act as a filter in that the action potential waveform from one muscle fibre does not reach them both at the same time (Basmajian & DeLuca, 1985). The time difference is a function of the conduction velocity of the muscle fibre and, the inter-electrode separation (Basmajian & DeLuca, 1985). The bandwidth of the electrode filter function on the detected EMG signal has been found to increase as the inter-electrode separation distance decreases (Lyn et al., 1978; Moritani & Muro, 1987).

The detection area of an surface electrode is limited (Andreassen & Rosenfalck, 1978; Pollak, 1971; Zipp, 1982a; 1982b). As stated earlier, the signal amplitude decreases quickly as the electrode moves away from the signal source. Andreassen and Rosenfalck (1978) also found for bipolar electrodes, the sensitivity increases when the detection surfaces are perpendicular to the fibres. Arbitrary demarcation values have been proposed to define the pick up area of an electrode (Andreassen & Rosenfalck, 1978; Pollak, 1971). Pollak, (1971), suggested a demarcation point when the peak to peak value amplitude of the action potential diminishes to 10% and Andreassen and Rosenfalck, (1978), suggested a decrease of 25% in the amplitude.

Location of the Electrodes

As discussed earlier muscle tissue is anisotropic, therefore it is important to orientate the detection surfaces of the electrode with respect to the length of the muscle fibres. However the actual recommended location of the surface electrode in relation to the whole muscle varies. To position an electrode, Basmajian and DeLuca, (1985) prefer a location half way between the centre of innervation zone and the muscle tendon. Zipp (1982b), recommends a site equidistant from the attachment points, with electrode size and spacing adapted to the muscle size and the purpose of the investigation. Kramer et al. (1972), found the maximum activity is over the middle of the muscle, and different placements of the electrodes yielded different voltage readings for the same load. Therefore it is important to be consistent with electrode placement.

The reported locations for surface electrodes on abdominal muscles as used in previous studies are varied. For upper Rectus Abdominis examples of the reported location of the electrodes include, midway between the umbilicus and xiphoid process (Ekholm et al., 1979; Partridge & Walters, 1959; Stokes et al., 1989), at the centre of the uppermost segment (Gutin & Lipetz, 1971), centred over two segments immediately superior to umbilicus (Stanhope, 1987), and at the centre of third

segment above umbilicus (Flint & Gudgell, 1965). The reported location of surface electrodes on lower Rectus abdominis include centre of the lowermost segment (Girardin, 1973; Gutin & Lipetz, 1971; Flint & Gudgell, 1965; Partridge & Walters, 1959; Stanhope, 1987), five centimetres below umbilicus (Stokes et al., 1989) and immediately below umbilicus (Ekholm et al., 1979). For the External Oblique muscle the reported locations of surface electrodes includes at the end of ninth rib just below costal margin (Flint & Gudgell, 1965), between iliac crest and lower ribs (Ekholm et al., 1979), above the anterior half of iliac crest (Floyd & Silver, 1950) and between the seventh and eighth rib and semilunaris (Stanhope, 1987). The centre of a triangle bounded by the lateral edge of Rectus Abdominis, inguinal ligament and a line drawn between the Anterior Superior Iliac spine and the umbilicus was reported as the location of surface electrodes for the Internal Oblique (Floyd & Silver, 1950; Miller & Medeiros, 1987).

Noise and Crosstalk

The EMG signal is a combination of unwanted voltages known as noise and the signal from active muscle fibres itself (Kreifeldt & Yao, 1974). The problem of noise is important because noise is added to the signal before amplification and therefore will be increased along with

the wanted signal during amplification (Basmajian & DeLuca, 1985). Sources of noise can include electromagnetic fields, EMG equipment, cardiac electrical activity, and motion artifacts (Basmajian & DeLuca, 1985). Electromagnetic fields are signals from sources such as power lines, radio signals, and television (Lee & Mosley 1989) and may be reduced by the use of 50 Hz notch filters. The EMG equipment itself produces noise which that can be reduced to ignorable levels by cleaning the electrode surfaces and, using an amplifier with low noise (Basmajian & DeLuca, 1985). Cardiac electrical activity may be recorded when measuring from the torso (Basmajian et al., 1975). Motion artifacts are signals usually below 30 Hz and may be caused by disturbance at the electrode-tissue interface, as discussed earlier, or by movement of the wire leads connecting the electrodes to the amplifier (Miles et al., 1982), or skin potential varying as the skin is stretched (Tam & Webster, 1978). Abrasion of the skin causes the voltage to be shorted out (Tam & Webster, 1978).

As discussed earlier, one disadvantage of surface electrodes is cross-talk. Cross-talk is minimised by the use of bipolar electrodes with a differential amplifier (Basmajian & DeLuca, 1985), electrode size (Basmajian & DeLuca, 1985; Lyn et al., 1978; Zipp 1982b) and an

inter-electrode spacing suitable to the muscle size (Zipp, 1982a; 1982b).

Amplifiers

The amplitude of the EMG signal is generally less than two millivolts and must therefore be amplified in order to be useful (McLeod, 1973).

Noise, as discussed above, will also be amplified and thus will effect the quality of the EMG signal. Therefore such artifact must be removed or reduced to reasonable levels. The noise can be reduced by using a differential amplifier, subtracting the two input signals from a bipolar electrode configuration then amplifying, therefore ideally eliminating any common mode components such as noise (Lee & Mosley, 1989). However, not all noise is removed because the noise signal is not identical at both electrodes, and amplifiers can't subtract perfectly (Basmajian & DeLuca, 1985). Motion artifacts from movement of leads may be reduced by having the first stage of amplification as close as possible to the source of the signal, such as locating the preamplifier on the electrode (Klijn & Krogge, 1973; McLeod, 1973). When a relatively noise free signal is achieved, McLeod (1973) recommended to use as much amplifier gain (amount of amplification) as can be tolerated by the rest of the data retrieval system.

Amplification may alter the frequency characteristics of the signal (McLeod, 1973). To minimise waveshape distortion and attenuation of the signal source, the amplifier input impedance is recommended to be much larger (10 times greater) than the impedance of the source electrodes (McLeod, 1973).

Recording of the EMG Signal

To analyse the EMG signal it must be displayed and/or recorded. Methods include display on a oscilloscope, transfer to paper via chart recorder or storing on a frequency modulated tape recorder, although, the bandwidth of the recording device must be greater than the amplified signal (Basmajian & DeLuca, 1985). Basmajian and DeLuca, (1985), also describe storing EMG signals directly on digital storage media such as computer memory, disks or digital magnetic tape. This is done by digitisation. The signal is sampled at regular intervals and the amplitude value at each point is expressed as a binary value (power of two) and stored. The sampling rate is important and must be at least twice the value of the highest frequency component of the signal of interest (Basmajian & DeLuca 1985).

Therefore, surface electrodes can be considered as filters and their characteristics vary with the size of detection area and inter-electrode spacing, and the

characteristics of the electrode-electrolyte junction. The EMG signal is affected by the position of the electrodes relative to the fibre orientation, the distance between the muscle fibre and the electrode, and the location of the electrode in relation to the innervation zone. In the literature there are various reported locations of surface electrodes when recording EMG signal from abdominal muscles.

The amplifier should be designed and set so that there is minimum distortion of the wanted signal and removal of as much noise as possible. The EMG signal may be recorded using such methods as chart recorders, or digitised and stored on digital storage media such as computer memory.

Analysis of EMG

As discussed earlier, when a muscle contracts with increasing tension, the number of motor units recruited and the frequency of their firing rate changes. Consequently the EMG pattern which is detected from many motor units will change from a few motor unit potentials to an unpredictable "interference pattern" (Basmajian & DeLuca, 1985). So in order to gain some information from the signals a repetitive measurement of one parameter of the signal is made then that measurement is subjected to

statistical analysis (Basmajian & DeLuca, 1985). There are many different parameters which have been used and these include counting the number of zero crossings (Fusfield, 1971), a count of action potentials occurring in a fixed time interval known as the number of turns (Fuglsang-Frederikson, 1987), spectrum analysis (Moritani & Muro, 1987), and the root mean square value (Christensen et al., 1984; Schanne & Chaflin, 1970).

Integrated EMG

Another method is the use of integrated EMG (IEMG). The signal is fullwave rectified (inversion of the negative values so the total signal energy is included) then the integral (area under the curve) of the rectified wave is computed (Lee & Mosley 1989). Modifications of the signal which occur over time, may be seen by integrating over a fixed time period (Basmajian et al., 1975, Basmajian & DeLuca, 1985). The average rectified value can be obtained by dividing the integrated rectified value by the fixed time period (Basmajian et al., 1975).

The Relationship Between Force and Isometric Contraction IEMG

IEMG has been found, for non-fatiguing isometric contractions, to be linearly related to the force

produced by the muscle (Bigland & Lippold, 1953; Fuglsang-Frederikson, 1981; Milnar Brown & Stein, 1975; Viitasalo & Komi, 1978). But nonlinear relationships have also been reported (Bouisset et al., 1973; Bronks & Brown, 1987; Lawrence & DeLuca, 1983). Muscles with uniform fibre type composition were found to give linear results, whereas mixed fibre composition muscles gave nonlinear results (Woods & Bigland-Ritchie, 1983). The size of muscles influences their firing rate-recruitment schemes (Fuglsang-Frederikson, 1981). For small muscles the EMG to force relationship was found to be quasilinear (practically linear) whereas for large muscles the amplitude increases more than the force (Lawrence & DeLuca, 1983). Synergists are a problem in that the force measured is a net result of all muscles working not just the muscle being recorded for electrical activity. As force is increased the more likely a synergist is to be involved (Yang & Winter, 1983) and the less direct relationship any one muscle will have with the force produced. To maintain an isometric contraction as the force increases, it may be necessary to stiffen the joint using antagonist muscles. Thus the net force may not reflect the activity of the agonist only (Yang & Winter, 1983). For isometric isotonic contractions the relationship is linear but for isometric contractions where the tension is changing then the amplitude of the

signal rises faster than the force (Fuglsang-Frederikson, 1981). Bouisset et al. (1973) found for both conditions that a quadratic relationship was seen between IEMG and force multiplied by time.

Despite the possibility of a varying relationship the average rectified value is thought to be a good descriptor of force from 0 to 100 % of a maximum voluntary isometric contraction when recorded with surface electrodes (Phillipson & Larsson, 1988).

Methods of Comparing IEMG

IEMG numerical values should not be used directly to compare muscles or subjects as they are uniquely related to the particular muscle and subject (Dabrowska & Kedzior, 1985). To overcome this problem various methods have been used. A grading scale to classify levels of activity from low to high is used by Booth et al. (1980). Each muscle response was graded longitudinally within the same channel from low to high. Relative grades could then be compared across channels. A similar method was used by Flint and Gudgell, (1965). Another method, normalisation of the IEMG, is used to compare individual muscles relative output and different individuals (Echternach, 1985). Normalization of IEMG data eliminates the need to control for variability among subjects, and the variability seen in data from re-application of

electrodes to the same subject (Echternach, 1985). One method is to normalise the IEMG for each muscle, for a test exercise, to the IEMG for a standard signal such as the maximum voluntary contraction (Ekholm et al., 1979; Lawrence & DeLuca, 1983; Stanhope, 1987; Woods & Bigland-Ritchie, 1983). Another is to use the percentage of each muscle's IEMG in relation to the total IEMG of all the muscles (Viitasalo, 1983).

Anisometric Contractions

The discussion above has been in relation to isometric contractions. However, when the contraction involves a change in length of the muscle, an anisometric contraction, additional factors as well as those for isometric contractions must be considered as the relationship between the electrode and the active muscle changes with movement. The force output of a muscle is a function of its length (Kreighbaum & Barthels, 1985). Therefore to estimate the muscular force from EMG the length of the muscle must be accounted for (Huijing et al., 1985). The instantaneous center of rotation (where net torque is zero) is not fixed in most joints (Basmajian & DeLuca, 1985). A change in this will affect the moment (force multiplied by distance) of the tendon insertion. Therefore the IEMG for an anisometric movement cannot be equated directly with the force output. EMG

signals are also different for eccentric and concentric work (Bigland & Lippold, 1954; Komi, 1973; Schieber & Thatch, 1985). EMG amplitude is greater when a muscle is shortening and less when it is lengthening (Schieber & Thatch, 1985). Bigland and Lippold (1954), found that the slope of the relationship between IEMG and tension is greater when a muscle shortens at a constant velocity, than when it lengthens at the same velocity. However, Komi (1973) found that maximum IEMG remained constant during different velocities for concentric and eccentric contractions and the IEMG was also independent of the velocity of contraction particularly in concentric work.

Reproducibility of EMG Signal

As discussed earlier, with each electrode application the EMG signal is altered by differences in the geometric relationship of the electrode with the muscle and the quality of skin preparation. Therefore the EMG signal is unique each time the electrode is applied. However studies examining the surface electrode IEMG from maximal and submaximal isometric contractions between different test days have shown satisfactory reproducibility (Komi & Buskirk, 1970; Pancherz & Winnberg, 1981; Viitasalo & Komi, 1975). The factors which must be carefully controlled to allow the maximum possible reproducibility include precise relocation of

electrodes (Garnick, 1975; Komi & Buskirk, 1970; Viitasalo & Komi, 1975) interelectrode distance and electrode size (Komi & Buskirk, 1970), levels of skin resistance (Garnick, 1975) and careful replication of the movement speed, direction, and muscle length (Viitasalo & Komi, 1975).

Summary

In summary, EMG can be used to determine if a muscle, parts of a muscle or a group of muscles is active or inactive during a specific movement. The relationship between the EMG signal and the isometric muscle activity is monotonic in that when mechanical output increases so does the electrical output. The signal does reflect the force output of the muscle but it may also be affected by the detection procedure and activity from muscles not being monitored. EMG may be used to measure the amount of force a muscle is capable of producing for isometric contractions and for short nonfatiguing durations. Using normalised IEMG, comparisons of activity between muscles and subject to subject may be made. Grading of the level of EMG activity may be done by analysing the signal as a percentage of the total IEMG. The change of activity levels within specific muscles during a movement may be followed. Satisfactory reproducibility of surface

electrode IEMG between test days is possible for maximal and submaximal isometric contractions. However careful replication of electrode site, skin resistance and manner of movement is important.

CHAPTER 3:

GENERAL METHODS

INTRODUCTION

The study consisted of a primary series of three experiments examining the effects of pregnancy on the abdominal muscles' structure and function, and a secondary experiment validating a newly developed muscle test for abdominal muscles. The detailed method for the secondary experiment appears in Chapter 5 and will not be discussed further in this chapter.

EXPERIMENTAL PROTOCOL

The primary study determined, for primigravid women with a single foetus (maternal subjects), changes to the gross structure of Rectus Abdominis and the functional abilities of the abdominal muscles, each four weeks from 14 weeks gestation to term or until directed otherwise by the subject or her consulting physician. Maternal subjects were again tested at four and eight weeks post-birth. The maternal subject and her consulting physician were given participant information, and signed an informed consent form (Appendix I) before commencement of the study. The protocol for each testing session attended by the maternal subjects was as follows: -

- a) Subject Profile Data
- b) Muscle Test
- c) Electromyography
- d) Three-dimensional Photography.

Nullipara female university students were used as a control group. The control subjects were also tested each four weeks for a total of four test sessions. Further repeat test sessions were unable to be held due to the unavailability of the control subjects. The control subjects were given participant information and signed an

informed consent form (Appendix II) before commencement of the study. The protocol for each testing session attended by the control subjects was as follows: -

1. Subject Profile Data
2. Electromyography.

All subject profile data are presented in Appendix IV. All subjects were free to withdraw from the study at any time. The study was approved by the University of Wollongong Ethics Committee. All testing was conducted by the author at the Department of Human Movement Science, University of Wollongong, Wollongong N.S.W., Australia.

EXPERIMENTAL DESIGN

The following notes outline each procedure and the rationale of the procedure where necessary.

a) Subject Profile Data

The maternal subject's height, weight, exercise history for the previous four weeks, and pregnancy duration were noted. For the control group, the data included height, weight and age.

b) Muscle test

The maternal subject performed a muscle test assessing the abdominal muscles' ability to stabilise the anterior pelvis against a resistance. Further details of this test are found in Chapter 5.

c) Electromyography

The electromyographic protocol for control and maternal subjects was similar with the exception of skinfold data.

Skinfolds

The amount of subcutaneous adipose tissue beneath the recording electrodes, at each test session, was measured using skinfold thickness for each maternal

subject after location of the electrode site and before skin preparation. Skinfold data was collected only for the maternal subjects as abdominal subcutaneous adipose tissue was assumed to remain consistent for the control group over the period of the study.

Equipment

The EMG electrodes, amplifiers and software used, were part of Waveform Analysis System Package, version 2.0 (WASP) by Qantec Systems, University of Queensland, Australia. Preamplified surface electrode units (Model 820), consisting of two active electrodes at 1.5 cm centres and a single reference electrode, as shown in Figure 1, were gelled and attached to prepared sites using disposable foam pads. The line of active electrode positionings were parallel to the fibre direction of the underlying muscle. The electrodes were connected to an AC amplifier (Model 810) where the raw signals were filtered (bandwidth 10 - 1000 Hz and a 50 Hz notch filter) and suitably amplified to enable onscreen monitoring. The output from the amplifier was converted from an analogue to digital signal (WASP Interface, Model W10) and passed to an IBM compatible personal computer where it was sampled at 1000 Hz and stored.



Figure 1. Surface Electrode Units

Electrode Sites

Electrode sites were marked with water soluble pen on the upper Rectus Abdominis, lower Rectus Abdominis and the External Oblique as follows: -

Rectus Abdominis: The electrode site was centred on the palpated muscle belly, midway between the sternum and the umbilicus as measured by the author for upper Rectus Abdominis, and midway between the pubis and the umbilicus as measured by the author for lower Rectus Abdominis.

External Oblique: The electrode site was five centimetres above the Anterior Superior Iliac Spine.

The skin at each electrode site was prepared by shaving, abrading with emery paper and wiping with alcohol.

The width of the linea alba changed throughout pregnancy with the separation of the Recti. The altered, more lateral position of the Rectus Abdominis was determined by palpation and location of the electrodes suitably altered at each test session for the maternal subjects.

Recordings

The recorded EMG signals included background, submaximal contraction and during selected abdominal exercises. These are described as follows: -

Background signal: Levels were established at the beginning of each test session by recording the supine subject at rest.

Submaximal Voluntary Isometric Contraction (subMVIC): A subMVIC was performed by the subject with verbal encouragement but no external resistance from the author. The instructions given to the supine subject were to tighten her abdominal muscles 'as hard as possible' without raising her head from the plinth. This procedure

was approved for maternal subjects by a Medical Practitioner on the staff of the Human Movement Science Department.

Selected Abdominal Exercises: The subjects were asked to perform, to the best of their own level of ability, five repetitions of four abdominal exercises, as described in Appendix III, with rest periods between each repetition. Each exercise was described to the subject prior to execution, and practice sessions were allowed. The exercises were performed slowly to verbal instructions given by the author. No attempt was made to encourage the subjects to perform the exercise beyond the subject's desired level.

Analysis

WASP software (Carlyon, 1987) was used for EMG waveform analysis. For each trial, a 500ms period of representative EMG activity was chosen by the author. A description of the methods used by the author to determine the sample is given in each applicable section. The EMG signal sample was reduced by the amplification factor used to enable onscreen monitoring, signal offset removed, rectified then integrated (IEMG) and the average volts*second determined for the selected sample. This value was then recorded as test session data.

d) Three-Dimensional Photography

The three-dimensional position in space of markers located on the subject's abdomen were used establish the gross structure of Rectus Abdominis.

Subject Position

The position of the uterus under the influence of gravity may be different when the subject is standing or supine due to the weight force from the gravid uterus on the lower anterior abdominal wall. Thus as the direction of this study was to relate structural to functional changes for the abdominal muscles performing predominantly supine exercises, all structural data collection was performed while the subject was supine.

Rectus Abdominis Separation Criteria

The linea alba separates the Recti as described earlier in Chapter 2. In previous studies, the criteria (Noble, 1982), of two centimetres for evidence that separation is greater than normal, has been used (Boissonnault & Blaschak, 1988; Bursch, 1987). However, the normal width of the linea alba as described by Poirier (1912), is 6 to 8 mm at the sternum, 15 to 25 mm at umbilicus, and a linear raphe only from a point 1-3 cm below umbilicus. As it is very difficult to discern by palpation the difference between separation and the

valley between two muscle bellies when the width is less than 10mm, for this study a criteria for separation was developed based on Poirier's measurements but modified for palpation difficulties. The criteria for Rectus Abdominis separation was a 10 mm or greater width above and below umbilicus and 15mm or greater width at umbilicus.

Photography

The abdomen was photographed, and photographs analysed, as described for the Direct Linear Transformation three-dimensional static photography method detailed in Chapter 2. All film was processed by the technical staff of the Department of Human Movement Science, University of Wollongong. Digitising of photographs was performed by the author.

STATISTICAL METHODS

Due to the longitudinal nature of the study, investigating changes over time, the statistical test chosen was a repeated measures analysis of variance. This test allows for possible dependence within values (Russell, 1991). However for the maternal group there were low subject numbers and missing values due to early deliveries and withdrawal on medical advice. Therefore repeated measures analysis of variance could not be used for the complete maternal group data. An alternative method to determine whether there were changes over time was to use Student t-tests on the differences between test sessions for paired data, and an analysis of variance (ANOVA) for overall study data (Gehring, 1978). The results from these statistical tests must be treated with caution because the data were unlikely to strictly satisfy the statistical test assumptions (Russell, 1991). Statistical computer software used for calculations included Minitab version 5.1 (Ryan et al., 1985) and SPSS-X (SPSS Inc, 1988).

CHAPTER 4:

VARIATION IN THE GROSS STRUCTURE OF RECTUS ABDOMINIS
AS MEASURED BY THREE-DIMENSIONAL PHOTOGRAPHY

INTRODUCTION

The aim of the work in this chapter was to investigate changes in the gross structure of a representative abdominal muscle, Rectus Abdominis, during pregnancy and the immediate post-birth period as a basis for discussion of the functional capabilities of the muscle during this time. The Rectus Abdominis is a superficial abdominal muscle, as shown in Figure 2, and may be palpated without difficulty. Therefore the gross structure of the muscle may be outlined on the skin. Since the surface of the human body is highly irregular and complex, any detailed representation of the muscle's form would involve a large number of measurement points (Reed & Garrett, 1971). In addition, the abdomen of a pregnant female is continually changing shape to and beyond term. Thus, to obtain an exact replica model of the gross structure of the Rectus Abdominis would be very complex and time consuming. Therefore, to achieve the aim of this study, a simpler three-dimensional model of the Rectus Abdominis was constructed which included the angles of insertion in the coronal and sagittal planes, medial edge muscle length and separation.

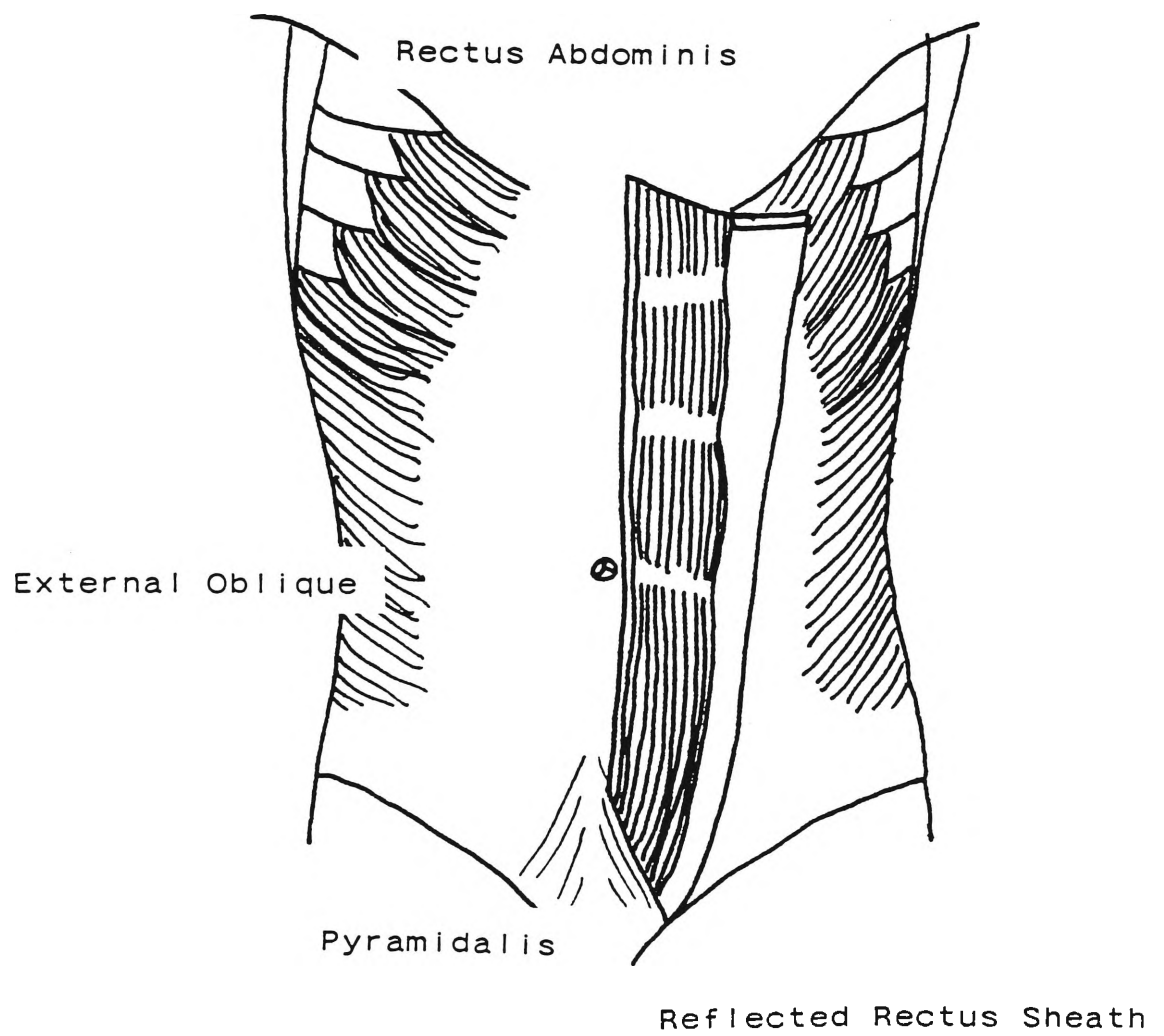


Figure 2. Superficial Abdominal Muscles

METHODS

The gross structure of the Rectus Abdominis was determined from anatomical labels marked with ink on the skin of the maternal subject. To position the subject's labels, with the subject supine and head raised, the medial edge of the right and left Rectus Abdominis was palpated 4.5 cm above and below umbilicus, and at umbilicus. The Recti medial edges were marked where the separation between the Recti muscle bellies, above and below umbilicus was 10mm or greater, or 15 mm or greater at umbilicus. With the subject relaxed, the medial edge of the superior and inferior attachment points of the right Rectus Abdominis were palpated and marked. On the pubis, pubic hair was gelled flat and the muscle attachment point was marked on adhered tape. The most anterior point of the abdomen in the sagittal plane was also marked (vertex).

A flexible measuring tape was used to manually record the Recti separation to the nearest millimetre at the three marked sites along the linea alba, and the right Rectus Abdominis medial edge length. Two measurements were taken and the average recorded.

The Direct Linear Transformation (DLT) method for three dimensional photography was used to establish the position in space for the subject's labels, with a

modified Marzan and Karara (Marzan & Karara, 1975) method of analysis for static photographs. A reference structure, seen in Figure 3, was constructed from 4mm diameter steel rod. Rigidity was ensured by diagonal wire braces held taut by turn clasps. Sixteen control points were marked on the steel rods and their x, y and z placement from a selected origin was measured.



Figure 3. Reference Structure and Subject

It was critical to the DLT method that the cameras were not moved once the control points had been photographed. To avoid this possibility and errors due to inaccurate

placement of reference structure and subject photographs in the digitising system, the reference structure was constructed to be placed over the subject. Each photograph therefore contained both the reference structure and the labeled subject. The four legs of the reference structure were stabilised in two wooden braces placed beneath the supine subject's cervical spine and thighs as seen in Figure 3.

Two tripod-mounted 35mm SLR cameras (Praktica MTL 5B) fitted with 50 mm lens were positioned to the right and left of the subject with all subject labels and reference control points being visible in each camera's field of view. Black and white 125 ASA film (Ilford FP4) was used at F stop 2.8 and a 1/30 second shutter speed. Black and white, 20 by 25 centimetre photographs were made and used for further analysis.

The control points and subject labels from both cameras were digitised (Sonic Digitiser GP-8) twice and stored on an IBM compatible personal computer. The DLT computer programme (Atkinson, 1988), using the measured x,y,z placement from the origin of the control points, and digitised data from the control points and subject labels, gave the x,y,z coordinates of the subject labels.

The gross structure model for Rectus Abdominis given in Figure 4 was constructed as follows.

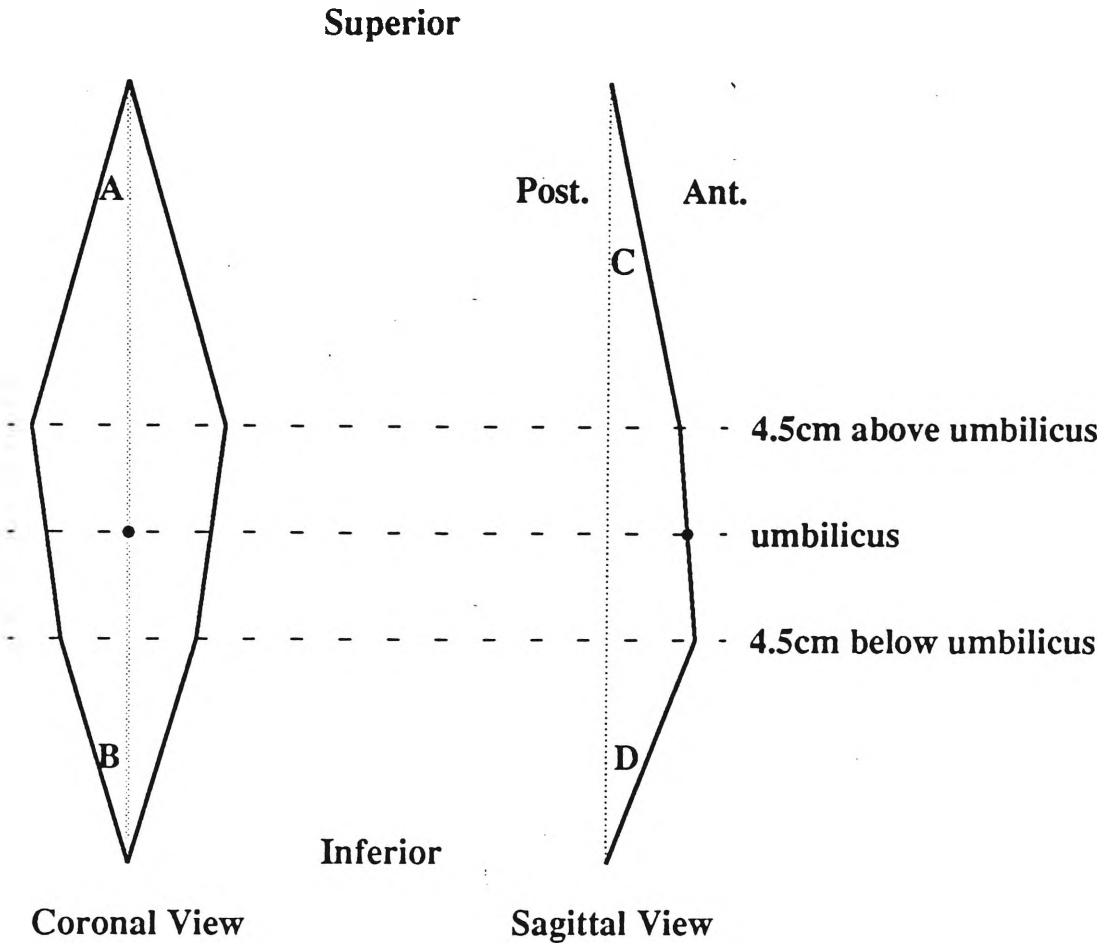


Figure 4. Model of Rectus Abdominis Structure. Solid lines represent muscle whereas the dotted line indicates the normal position of the linea alba.

The distance (r) between any two points located at x_1 , y_1 , z_1 and x_2 , y_2 , z_2 was calculated using equation 1.

$$r^2 = x^2 + y^2 + z^2 \text{ (Eq.1)}$$

where $x = x_2 - x_1$, $y = y_2 - y_1$, and $z = z_2 - z_1$ (Barham, 1978). Angles A, B, C and D were calculated using equation 2.

$$\cos \theta = (a^2 + b^2 - c^2) / (2ab) \text{ (Eq.2)}$$

where the θ is the angle of intersection between two sides of a triangle with side lengths a,b,c (Jones & Couchman, 1982). The average of distances between subject labels resulting from each digitisation were recorded. Where film data was unavailable due to photographic technical errors, manual measurements were used. The accuracy of DLT procedure was determined by comparison of actual distances between control points and the calculated distances.

The Rectus Abdominis model was used to establish the following for each subject:

- a) The medial edge length of the right Rectus Abdominis,
- b) The length of Rectus Abdominis at each test session normalised as a percentage of Rectus Abdominis length at the first test session where there were no external signs of macroscopic structural changes due to pregnancy,
- c) The separation of Rectus Abdominis 4.5 cm above and below the umbilicus and at umbilicus,
- d) The superior and inferior Rectus Abdominis angle of attachment in the coronal and sagittal planes.

The pooled results were analyzed by an ANOVA with Scheffé post-hoc statistical tests, $p < 0.05$ (Gehring, 1978).

RESULTS

The mean error in reconstructed lengths between control points expressed as a percentage of actual length was 1.02 ± 0.374 percent.

The mean and standard deviation (SD) of the length of the medial edge of right Rectus Abdominis (absolute and normalised values) with the number of subjects (N) used in each calculation are given in Table 1. One subject, for her first test session at 22 weeks had visible changes in abdominal shape and was therefore excluded from the Rectus Abdominis normalised length calculations.

Table 1. Mean (and SD) of Absolute and Normalised Rectus Abdominis Medial Edge Length

Week	Absolute (cm)	N _a	Normalised (%)	N _b
14	33.9 (0.1)	2	1.00 (0.0)	2
18	32.8 (1.3)	4	1.00 (0.001)	4
22	34.7 (0.7)	3	1.06 (0.051)	3
26	37.0 (2.0)	6	1.09 (0.057)	5
30	37.2 (2.7)	5	1.12 (0.070)	4
34	37.7 (2.1)	5	1.14 (0.049)	4
38	38.4 (2.7)	3	1.15 (0.027)	2

a number of subjects in absolute length calculations
b number of subjects in normalised length calculations

There was significant change ($p < 0.05$) in absolute and normalised Rectus Abdominis lengths between 14 to 38 weeks. The length of Rectus Abdominis was not recorded post-birth as it is unknown, as discussed previously in Chapter 2, whether the intramuscular connective tissue and tendinous attachments of the muscle increased in length during pregnancy, and this was not detectable by palpation in the post-birth period.

Recti separation above, at, and below umbilicus with the means highlighted is presented in Figure 5. Significant change ($p < 0.05$) was seen between weeks 18 to 30 for separation above and at umbilicus, and between weeks 22 to 38 for separation below umbilicus. Further significant increases ($p < 0.05$) in separation above umbilicus were seen from week 30 to week 38, and in separation at umbilicus from week 26 to week 38. The mean Recti separation at 38 weeks gestation was 62 mm above umbilicus, 47 mm at umbilicus and 32 mm below umbilicus. Recti separation at all sites showed significant ($p < 0.05$) narrowing between 38 weeks gestation and four weeks post-birth, to week 22/26 levels.

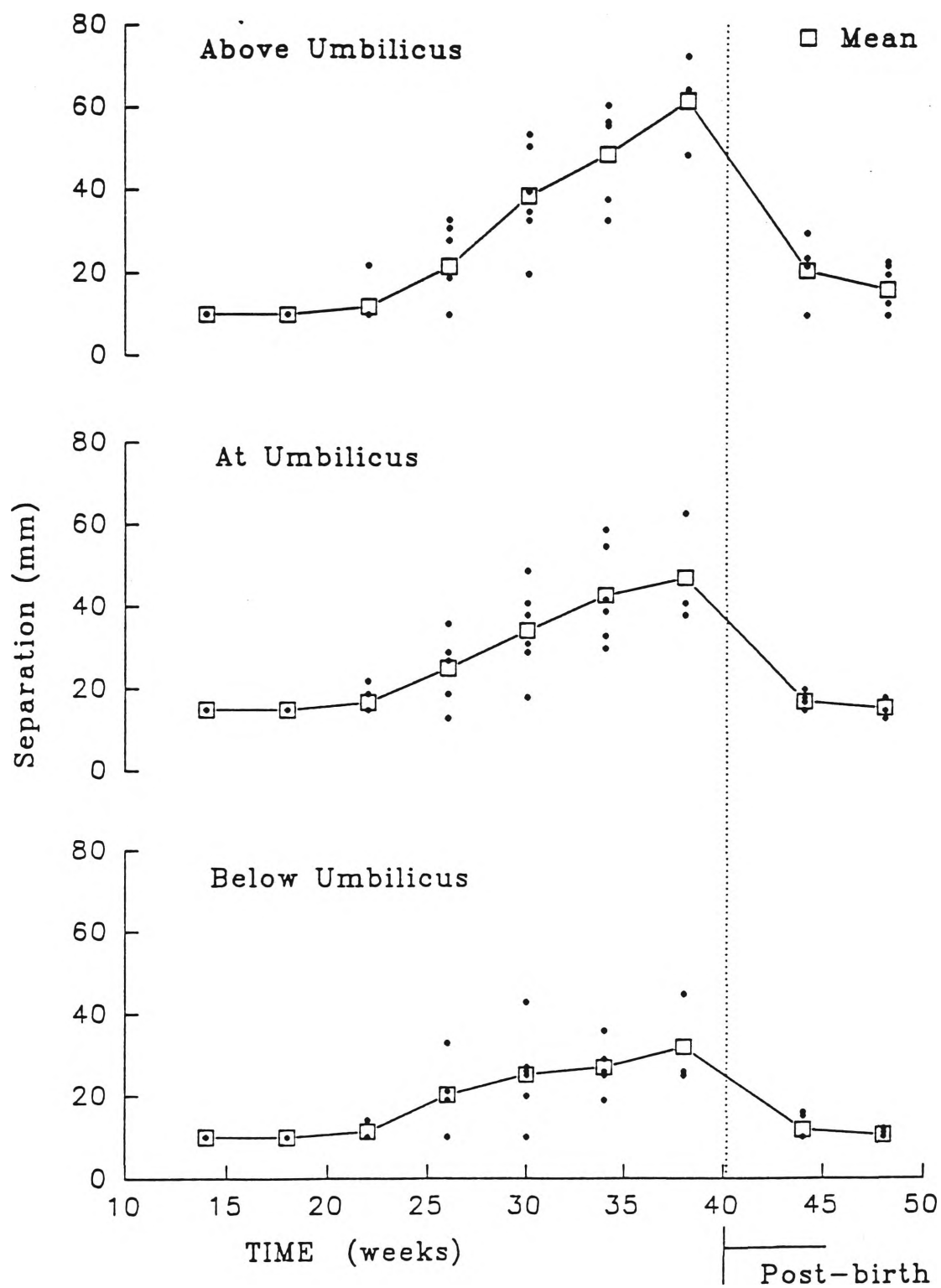


Figure 5. Scatterplot of Recti Separation

The calculated mean and standard deviation (SD) of the Rectus Abdominis angles of insertion in the sagittal and coronal planes, as shown in Figure 4, are presented in Table 2. The superior and inferior coronal, and superior sagittal angles of insertion showed significant change ($p<0.05$) between 18 to 30 weeks. The inferior sagittal angle of insertion showed significant change ($p<0.05$) between 18 to 26 weeks. For all angles of insertion significant changes ($p<0.05$) also occurred over weeks 26 to 38. Calculation of post-birth Rectus Abdominis angles of post-birth were unable to be made as Rectus Abdominis muscle length was not available.

Table 2. Mean (and SD) of Rectus Abdominis Angle of Insertion

Week	Insertion Angle (degrees)			
	Sagittal		Coronal	
	Superior	Inferior	Superior	Inferior
14	5 (1)	7 (1)	0 (0)	0 (0)
18	5 (2)	7 (3)	0 (0)	0 (0)
22	10 (1)	16 (2)	1 (2)	1 (2)
26	12 (3)	20 (5)	4 (3)	4 (2)
30	14 (4)	23 (6)	7 (3)	5 (3)
34	18 (5)	26 (6)	9 (3)	6 (3)
38	24 (6)	33 (2)	10 (3)	10 (4)

DISCUSSION

A simplified model of the Rectus Abdominis gross structure was constructed during pregnancy and the immediate post-birth period. The model included for the right Rectus Abdominis, the muscle medial edge length and the superior and inferior angles of insertion in both the coronal and sagittal planes. Also the Recti separation was measured at three points along the linea alba. The medial edge length was chosen as being representative of Rectus Abdominis muscle length for this discussion. An investigation as to the relationship between the lateral edge, medial edge and central muscle length was beyond the scope of this study.

Length of Rectus Abdominis

The mean length of the medial edge of the right Rectus Abdominis at 14 weeks gestation (where there was no external evidence of pregnancy) was 33.9 ± 0.1 cm. This result was similar to the mean abdominal length in non-pregnant subjects of 31.85 ± 2.789 cm found by Fast et al. (1990) and for the mean linea alba length of 33 cm described by Poirier, (1912).

The right Rectus Abdominis mean medial edge length in the supine subject increased significantly ($p < 0.05$) to 38.4 ± 2.7 cm at 38 weeks gestation. An increase in

length was also found by Fast et al. (1990), who found in pregnant subjects, with a mean gestation of 38 weeks, an increase in abdominal muscle length to 43 ± 4.031 cm. However Fast et al. (1990) assumed the midsagittal abdominal length to be equal to abdominal muscle length with no allowance for abdominal muscle separation during pregnancy. This would account for their larger values.

The abdominal muscles are often anecdotally described as being stretched or overstretched during pregnancy and are therefore incapable of producing normal tension because they are at a physiological disadvantage due to thinning (Blankfield, 1967; DeSanto & Hassid, 1983; Gleeson & Pauls, 1988; Shrock et al., 1981). Animal studies on Rectus Abdominis during pregnancy have shown hypertrophy (not thinning) of the muscle fibres which was thought to be in response to the increased workload of pregnancy (Lalatta Costerbosa et al., 1987 & 1988; Martin, 1979). Human skeletal muscles are known to hypertrophy in response to increased exercise workloads (Kreighbaum & Barthels, 1981) and, although human Rectus Abdominis response to increased functional workloads during pregnancy is unknown, animal studies and other human skeletal muscles' response to increased workload indicates a possible hypertrophic response and therefore resulting in no reduction in the amount of tension produced. Further investigation into the adaptive

response of the human Rectus Abdominis in pregnancy in relation to muscle cross-sectional area is warranted to resolve this question of stretching with resultant thinning.

It is known that an overstretched muscle is unable to produce normal amounts of tension (Gowitzke & Milnar, 1987) and as stated above, the Rectus Abdominis is commonly anecdotally described as being overstretched during pregnancy. This present study showed a maximum mean normalised length for the medial edge of Rectus Abdominis of 115% at 38 weeks gestation. The length of Rectus Abdominis measured included intertendinous connections and attachments. The effect of pregnancy on skeletal muscle connective tissue in humans is unknown. However for this discussion it will be assumed that the increase in Rectus Abdominis length is a reflection of the muscle fibre length. An 115% skeletal muscle fibre length is unlikely to greatly reduce the capability of the muscle to produce tension for two reasons. Firstly, when a muscle is suddenly stretched, parallel fibred muscles produce over 90% of maximum active tension at 115% of optimum muscle length (Kaufman et al., 1989) which for parallel fibred muscles is near resting length (Gowitzke & Milnar, 1988). Secondly, the present study found that this increase in length during pregnancy occurs over a period of approximately 22 weeks and

therefore the stretch is applied over time. Longitudinal studies on animals have shown adult skeletal muscle fibres add sarcomeres to their length when stretched over time. The maximum active tension is increased relative to controls and this maximum tension is developed at the new length (Williams & Goldspink, 1978). Similar studies have not been done on human skeletal muscle. However, human calf muscles stretched by serial casts applied for seven days showed significant increases in length (Mosely, 1989). Therefore, the human Rectus Abdominis may increase in length and maintain maximum active tension in response to the long term stretch of pregnancy. The increase in Rectus Abdominis medial edge length of 115% seen in the present study, therefore is unlikely to greatly reduce the ability to produce tension within the muscle. Thus functional deficits of the abdominal muscles during pregnancy and immediate post-birth may result from factors other than a change in muscle length.

Separation of Rectus Abdominis

For all subjects, Recti separation was not evident at week 14 gestation. By week 22, commencement of separation was seen in some subjects at each site. While all subjects showed Recti separation above umbilicus at week 30, at umbilicus by week 26 and below umbilicus by week 34. Post-birth four weeks, four out of six maternal

subjects had Recti separation above umbilicus, 5/6 at umbilicus and 3/6 below umbilicus. The absence of Recti separation in the first trimester, in conjunction with an increased incidence of separation as the pregnancy progressed, and reduced incidence post-birth was also found by Boissonnault and Blaschak, (1988). Other work by Spence (1978) showed Recti separation in 50% of subjects six weeks post-birth although the site of separation was not noted.

All subjects in the present study showed separation below umbilicus at 38 weeks. In an earlier study, Boissonnault and Blaschak (1988), found only 11% of subjects had separation below umbilicus in their third trimester. They did note however, a higher incidence of separation would have been found if the criteria for separation had approached the normal linea alba width at this point rather than the Noble (1982) criteria. The lower degree of separation found below umbilicus relative to the other sites was possibly due to increased reinforcement of the anterior rectus sheath below the arcuate line by aponeuroses from Transversus Abdominis, and External and Internal Oblique (Boissonnault & Blaschak, 1988).

A correlation has been proposed between weak, low tone abdominal muscles and the presence of Recti separation (Blankfield, 1967; Boissonnault & Blaschak,

1988). The subjects involved in this study were primarily conscientious exercisers (Appendix IV) throughout their pregnancies and thus, the majority could be considered to have well toned abdominal walls. Therefore Recti separation would be expected to be minimal. However, significant Recti separation ($p < 0.05$) was found at all sites and reversal of separation, although significant ($p < 0.05$) was not complete by eight weeks post-birth. Therefore the results for this study indicate Recti separation is not solely dependent on the abdominal muscle tone of the maternal subject.

In contrast it is also thought, abdominal exercise during pregnancy will possibly exacerbate the Recti separation (DeSanto & Hassid, 1983; Shearer, 1981; Shrock et al., 1981). In the present study there were insufficient subject numbers to statistically examine the incidence of separation between high and low frequency exercisers. However the observation was made that there was no apparent difference in separation incidence or size for frequent exercisers in comparison to infrequent exercisers. In fact the one subject who showed no separation until week 30 continued working as an aerobic class instructor until week 34 gestation. The question of whether abdominal exercise during pregnancy will exacerbate Recti separation remains unresolved.

Rectus Abdominis Angles of Insertion

Kapandji, (1974), describes the Rectus Abdominis as a powerful trunk flexor muscle operating by a lever system through the lumbosacral and thoracolumbar joints. The Rectus Abdominis' normal line of action, as seen in Figure 2, is aligned vertically from the costal margin to the pubis (Kreighbaum & Barthels, 1981; Kapandji, 1974). By 30 weeks gestation in this study however, the angle of

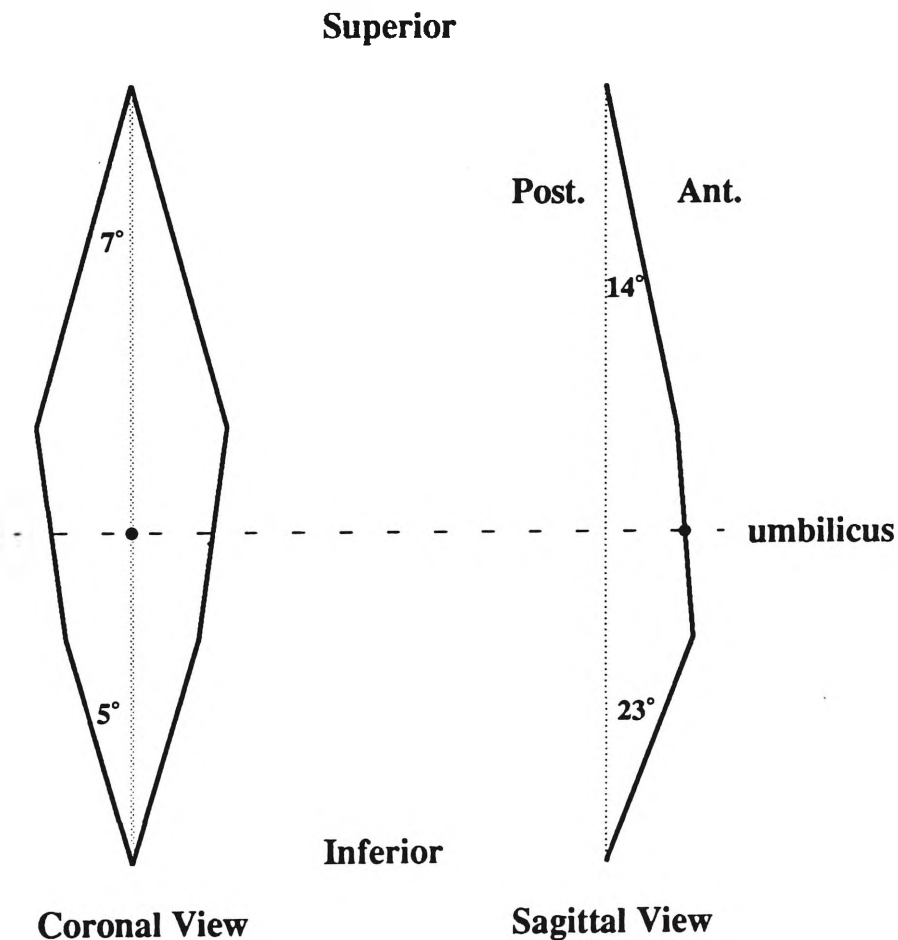


Figure 6. Right Rectus Abdominis Angles of Insertion At
Thirty Weeks Gestation

insertion in the coronal and sagittal planes for Rectus Abdominis had significantly ($p < 0.05$) altered and the muscle line of action would therefore be deviated laterally and anteriorly as shown in Figure 6.

The torque a muscle can produce is related to the line of action of the muscle (Kreighbaum & Barthels, 1981). The force diagram for Rectus Abdominis in the sagittal plane at the thoracolumbar and lumbosacral joints is seen in Figure 7. The normal angle of insertion is assumed to be 0^0 for this study.

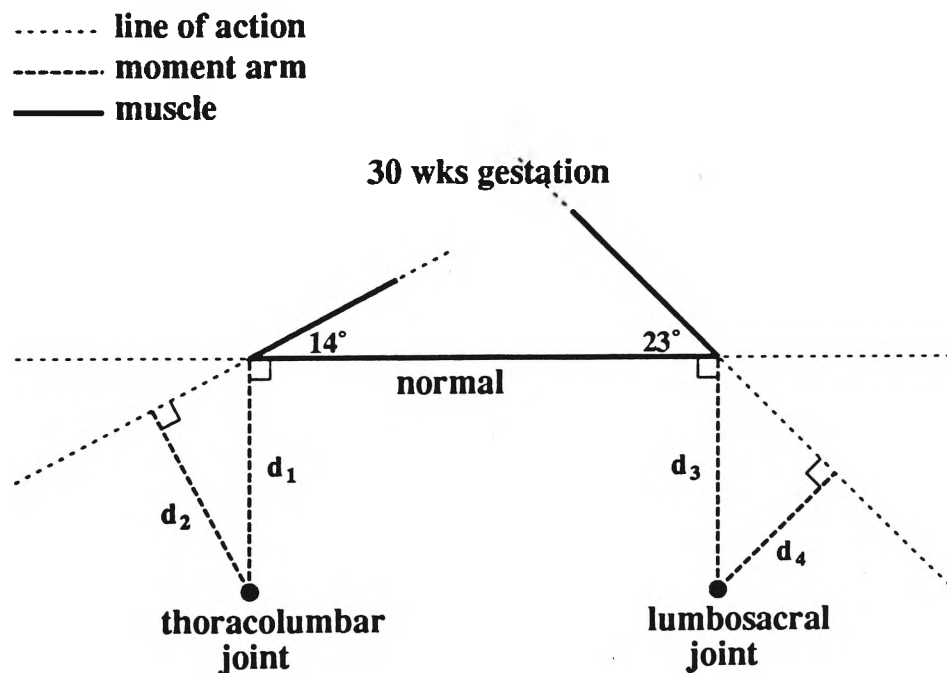


Figure 7. The Normal and 30 Weeks Gestation Line of Action for Rectus Abdominis in the Sagittal Plane about the Thoracolumbar and Lumbosacral Joint

From Figure 7 it can be seen the moment arm and therefore torque production by Rectus Abdominis force in this plane will be reduced at 30 weeks gestation. The ability of the Rectus Abdominis to flex the trunk is therefore possibly reduced. The minimum change in angles of insertion at which reduced torque production for Rectus Abdominis will have a demonstrable affect on the functional capacity of Rectus Abdominis is unknown.

Summary

The results of this study showed that, Recti separation at three sites and angles of insertions of the right Rectus Abdominis were significantly ($p < 0.05$) altered between week 18 to 30 with further significant ($p < 0.05$) change in angles of insertion and Recti separation above and at umbilicus between 30 to 38 weeks. Rectus Abdominis medial edge length increased significantly ($p < 0.05$) between week 14 to week 38. The Recti separation was shown to be reversing although not complete at eight weeks post-birth. The change in Rectus Abdominis length, although significant, may not necessarily reduce the tension produced by the muscle. However the torque production and therefore the functional capacity of Rectus Abdominis to produce flexion movement may be reduced due to the change in the muscle's line of action. Further investigation of Rectus

Abdominis muscle cross-sectional area during pregnancy, the effect of pregnancy on abdominal skeletal muscle connective tissue, and of the change in functional muscle capacity to produce movement in relation to moment arm length changes for Rectus Abdominis is warranted.

CHAPTER 5:

THE ABILITY OF THE ABDOMINAL MUSCLES TO
STABILISE THE PELVIS

INTRODUCTION

The results of the previous chapter have shown that the structure of the Rectus Abdominis was significantly ($p < 0.05$) altered throughout pregnancy with some resolution of these changes seen by week eight post-birth. In this chapter, attention will be directed at determining the degree of functional deficit produced by these musculoskeletal changes.

One function of the abdominal muscles is to stabilise the anterior rim of the pelvis against a resistance such as gravity (Floyd & Silver, 1950). Abdominal muscle control of the anterior pelvic rim position is also seen in the posterior pelvic tilt movement (Shearer, 1981). An assessment of the ability of the abdominal muscles to maintain a posterior pelvic tilt against a resistance is therefore, in effect, assessing the ability of the abdominal muscles to stabilise the pelvis (Kendall & McCreary, 1983).

A method used to assess skeletal muscle function *in vivo* is the muscle test (Lamb, 1985). A common muscle test to assess abdominal muscle strength is the double leg lowering test (Kendall & McCreary, 1983; Lacote et al., 1987). However the strength grade results of this test are subjective (Smidt et al., 1987), as they are based on the examiner's subjective determination of the

angle between the lower limbs and the plinth and the point at which the pelvis begins to antevert. Also the double leg lowering test will only identify wide differences in strength capabilities (Smidt et al., 1987) and does not have an equivalent range of resistance to that of abdominal muscle strength capability (Smidt & Blanpied, 1987).

A muscle test (MT) to assess abdominal muscle strength which addresses some of the above difficulties, has been developed by physiotherapists (Hunt & Henley, 1989) and was utilised in this chapter. The MT is based on assessing the ability of the abdominal muscles to maintain a posterior pelvic tilt at increased levels of difficulty. Validation of the MT using non-pregnant subjects is presented in Part I of this chapter.

The aim of the work presented in Part II of this chapter was to investigate the changes in the ability of the abdominal muscles to stabilise the pelvis during pregnancy and the immediate post-birth period. The investigative technique used was the MT as designed by Hunt and Henley, (1989).

Part I.

MUSCLE TEST VALIDATION

For a MT to be useful it must include face validity, that is measuring what it was intended to measure, and content validity, which is the ability of the test construction to reflect anatomical, physiological and kinesiological principles (Lamb, 1985). The aim of Part I was to validate this MT by i) examining content validity in determining the relationship between the level of difficulty of the test and the electromyographical output (EMG) of the abdominal muscles and ii) determining face validity by examining the functional interrelationship between the individual abdominal muscles during the MT.

METHODS

Subjects

Twenty-two male and female university students volunteered for the project and signed an informed consent form (Appendix V). Excluded from the project were subjects with a history of lower back injury, recent abdominal surgery, or those who exhibited excessive subcutaneous abdominal adipose tissue. For each subject, age, height, weight and the average number of exercise sessions per week they had participated in for the previous three months were noted. Table 3 summarises this data. An ordinal scale (as shown in Table 4) was used for the number of exercise sessions per week.

Table 3. Subject Data.

	Female		Male	
	Mean	Range	Mean	Range
Age (years)	19.4	18-28	21.9	18-28
Weight (kgs)	61.8	55-74	69.8	55-84
Height (cms)	170.3	158-181	174.6	166-181
	Median		Median	
	Median	Range	Median	Range
Exercise (sessions/week)	4	2-4	4	1-4

Table 4. Scale for Number of Exercise Sessions per Week

Scale	Definition
1	No exercise
2	Once a week
3	Twice a week
4	Three times or more per week

Electromyography

EMG waveforms were collected from the right abdomen at four sites as follows: -

Upper Rectus Abdominis; centred on the muscle belly midway between the sternum and the umbilicus,

Lower Rectus Abdominis; centred on the muscle belly, midway between the pubis and the umbilicus,

External Oblique; 5 cm above the Anterior Superior Iliac Spine (ASIS)

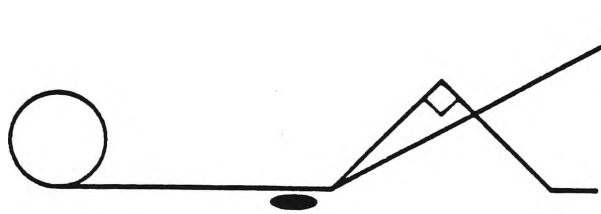
Internal Oblique/Transversus Abdominis: In the centre of a triangle bounded by the lateral edge of the rectus sheath, the inguinal ligament and a line joining the ASIS to the umbilicus (Floyd and Silver, 1950).

EMG equipment and skin preparation were as described earlier in Chapter 3.

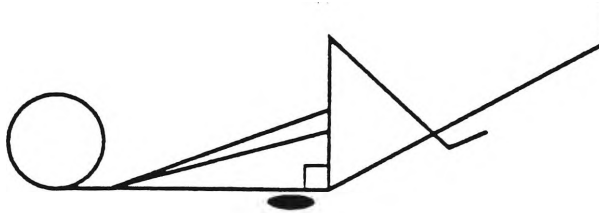
Each subject performed two subMVIC then participated in the MT, performing five trials at each level of difficulty in ascending order. Rest periods of approximately one minute were given between EMG recording. The right lower limb only was used for for Level 1, Level 2 and Level 3.

Muscle Test for Abdominal Muscles

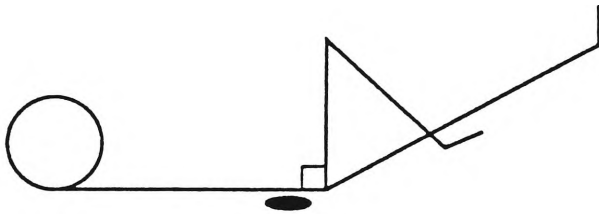
With the subject supine, knees flexed and feet flat on the surface, a child's sphygmomanometer cuff was placed horizontally under the lumbar spine, with its inferior edge level with the iliac crests. Prior to placement, the cuff was inflated to 10 mm Hg in order that baseline pressure measurements could be obtained. The cuff was connected to an electronic sphygmomanometer (Digital Blood Pressure Monitor, Model DS-115) whose signal was passed to a DC amplifier (band pass 10 - 1000 Hz), suitably amplified, and displayed on an oscilloscope (Trio 15 MHz Oscilloscope, CS-1560AII). The subject tilted his/her pelvis posteriorly, and the cuff pressure was recorded as the lumbar lordosis was reduced, indicating the baseline reading for future reference. To standardise the test position for retest at a later date, while the subject was crook lying with the knees at 90°, the distance between the ischial tuberosities and the



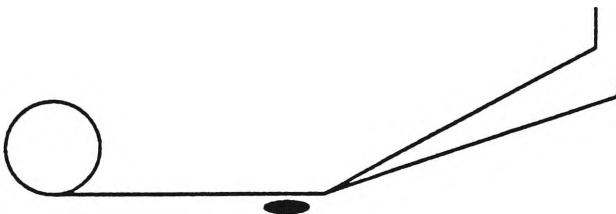
Level 1, in crook lying, knee flexed to 90°



Level 2, 90° of hip flexion, thigh supported by hands



Level 3, 90° of hip flexion, thigh unsupported



Level 4, 90° of hip flexion, lower both limbs

● Child's sphygmomanometer cuff

Figure 8. Muscle Test Levels of Difficulty

heel was recorded. The MT positions (Figure 8) were: Level 1, crook lying with the knees flexed to 90° ; Level 2, hips flexed to 90° and one thigh supported by the hands; and for Level 3 and Level 4, hips flexed to 90° and unsupported. At test positions Level 1 to Level 3, the subject reduced the lumbar spine lordosis, and while holding the posterior pelvic tilt, extended the right lower limb and lowered it to the horizontal plane. Under clinical examination conditions, this would then be repeated with the left lower limb. At Level 4 the subject reduced the lumbar spine lordosis, and while holding the posterior pelvic tilt, simultaneously extended both lower limbs and lowered them to the horizontal. The MT ceased when the baseline pressure reading recorded as above was not able to be maintained to within 10mm Hg. The last successfully completed test position was considered to be the level of ability of the abdominal muscles.

Analysis

The Pearson product moment correlation coefficient (r) was used to evaluate the relationship between MT result and the average number of exercise session per week.

Using WASP software (Carlyon, 1987), each trial was displayed, and a 500ms period of peak raw EMG activity was chosen by the author. The sample was then further

processed as outlined earlier in Chapter 3. For each muscle, the IEMG was normalised against IEMG of the average subMVIC (n-IEMG). Preliminary examination of the n-IEMG data revealed skewed data and a number of outliers, therefore nonparametric statistical tests were used. For each muscle, Wilcoxon matched-pairs signed-rank test (Gehring, 1978) was used to reveal any significant differences at the 0.05 level, between each MT Level.

The interrelationship between the abdominal muscles at each MT level of difficulty was examined by ordering in ranks the n-IEMG of each muscle from 1 (greatest) to 4 (least).

RESULTS

MT Level 2 or higher was reached by 77% of subjects, while Level 4 was reached by 18% of subjects. The noted exercise history showed 58% subjects exercised three times or more a week. There was no correlation between the MT result and the number of exercise sessions per week.

Five subjects were excluded from further analysis because they did not reach Level 2. The median n-IEMG value for each muscle and the rank is shown in Table 5.

Table 5. Abdominal Muscle Median n-IEMG Values and Rank (R)

Level	URA		LRA		EO		IOT	
	n-IEMG	(R)	n-IEMG	(R)	n-IEMG	(R)	n-IEMG	(R)
Level 1	75.6	2	86.9	1	48.6	4	49.7	3
Level 2	83.1	2	123.7	1	50.0	3	47.2	4
Level 3	114.5	2	192.5	1	55.4	3	54.5	4
Level 4	103.1	2	125.5	1	74.7	3	65.3	4

URA = upper Rectus Abdominis

LRA = lower Rectus Abdominis

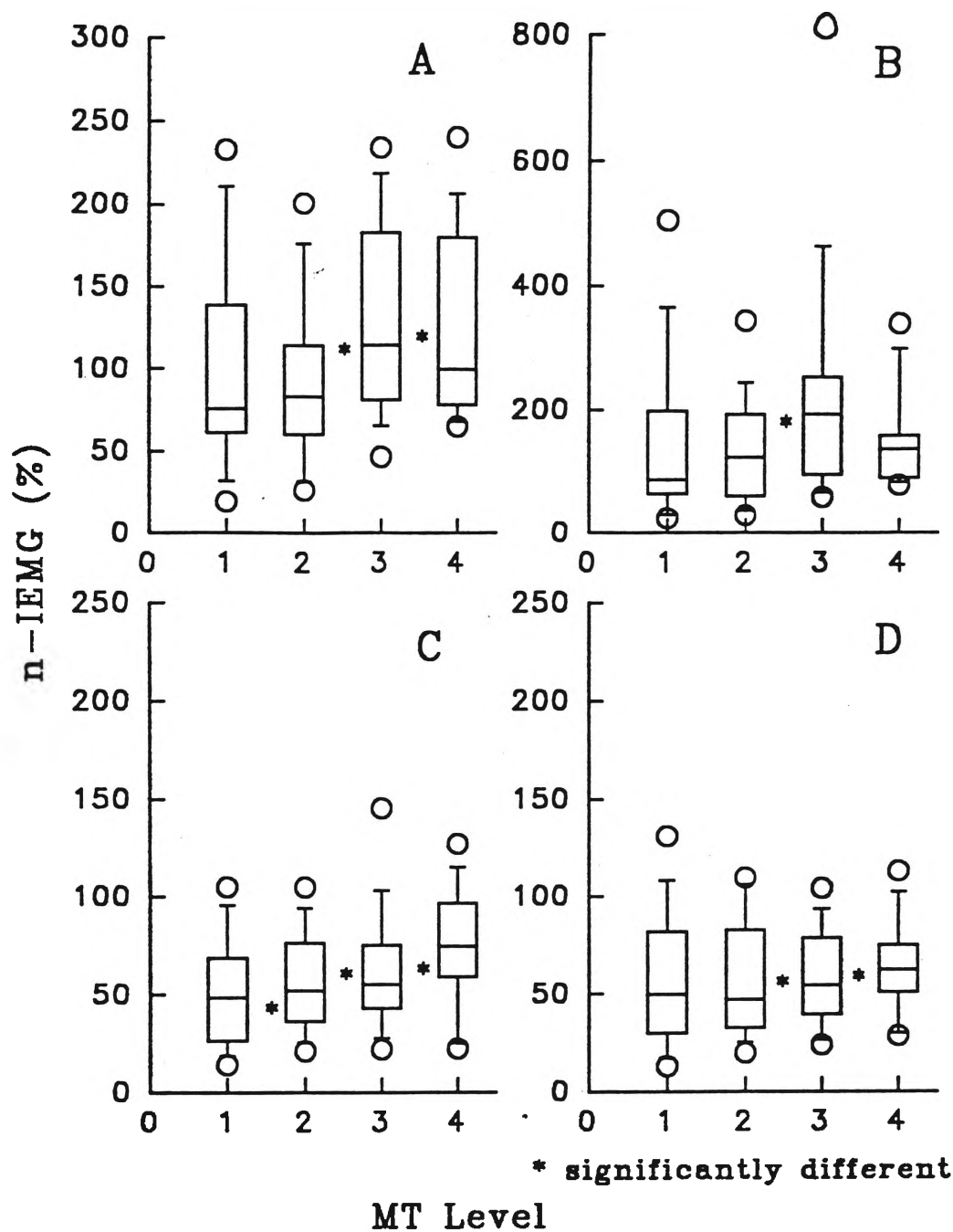
EO = External Oblique

IOT = Internal Oblique/Transversus Abdominis

Examination of the interrelationship between the abdominal muscles revealed that typically throughout the MT the lower Rectus Abdominis produced the greatest activity as a percentage of subMVIC, followed in order by upper Rectus Abdominis, External Oblique and Internal

Oblique/Transversus Abdominis, although at Level 1, the External Oblique n-IEMG value was slightly less than Internal Oblique/Transversus Abdominis. At Level 4, although upper and lower Rectus Abdominis were more active than the obliques, the relative contribution from the obliques as against the upper and lower Rectus Abdominis was increased in comparison to MT Level 1, 2 and 3.

A diagrammatical representation of the group n-IEMG data, with significant ($p < 0.05$) differences marked, is seen in Figure 9. As can be seen in Figure 9, the n-IEMG values recorded at upper and lower Rectus Abdominis, and Internal Oblique/Transversus Abdominis electrode sites for Levels 1 and 2 were similar. However, a statistically significant difference ($p < 0.05$) was seen for External Oblique between Level 1 and 2. A histogram of the differences between Level 1 and Level 2 (Figure 10) reveals this was not of practical value (Russell, 1991). Between Level 2 and 3, significant differences ($p < 0.05$) were found in n-IEMG for all muscles tested. At Level 4, the n-IEMG for upper Rectus Abdominis and lower Rectus Abdominis were less than Level 3, and for upper Rectus Abdominis this was significant ($p < 0.05$). However, for External Oblique and Internal Oblique/Transversus Abdominis the n-IEMG increased significantly ($p < 0.05$) at Level 4 relative to Level 3.



Note: 10th, 25th, 50th, 75th and 90th percentile points indicated by horizontal lines. Box encloses the 25th to 75th percentile. 5th and 95th percentiles are indicated by the symbol 0.

Figure 9. Boxplots of MT Level verses n-IEMG for A. upper Rectus Abdominis, B. lower Rectus Abdominis, C. External Oblique, D. Internal Oblique/Transversus

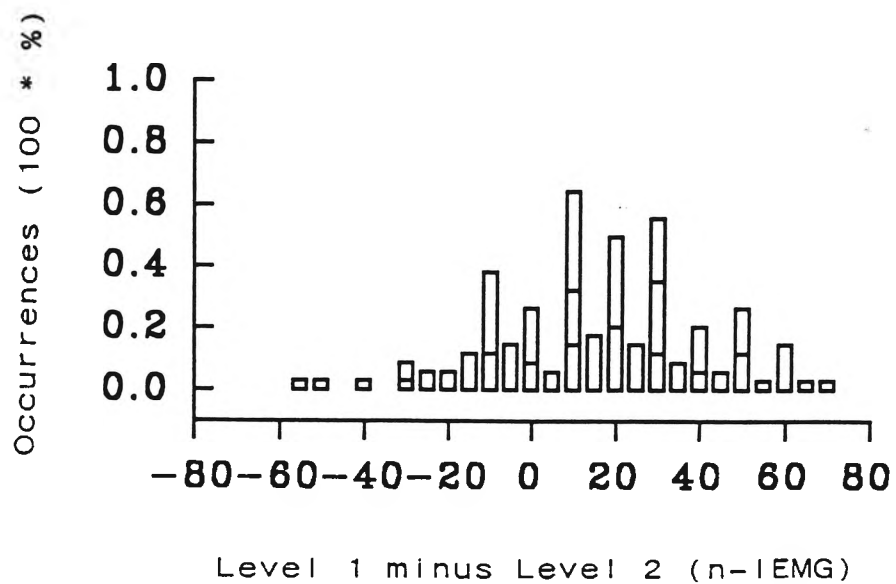


Figure 10. Histogram of the Differences between Level 1 and Level 2 for External Oblique

DISCUSSION

The MT for abdominal muscles presented in this study was developed by Hunt & Henley (1989) in an attempt to address some of the difficulties associated with the commonly used double leg lowering abdominal muscle test. These problems included subjective results and difficulty in grading weak muscles (Smidt et al., 1987; Smidt & Blanpied, 1987) as discussed previously. The Hunt and Henleys' (1989) MT was substantially different to a double leg lowering test in that results were not based on the examiners subjective assessment. Release of the posterior pelvic tilt position was detected by an objective change in pressure under the lumbar spine. Each grade was a separate pass/fail entity, therefore the examiner did not have to subjectively assess the grade reached. The lower range of abdominal muscle strength was included by the use of progressively difficult single leg lowering tasks.

Seventy seven percent of subjects were able to achieve MT Level 2 or higher, although as the MT level of difficulty increased, the number of successful subjects decreased. This would indicate that there was a wide range of abdominal muscle strengths among the subjects. However, there was no relationship between the amount of exercise performed each week and the MT result. This was

not unexpected as the type of exercise performed by the subjects varied and did not necessarily focus on increasing abdominal muscle strength.

A MT must measure what it is intended to measure and be valid in its content. The MT presented in this study was intended to measure the ability of the abdominal muscles to stabilise the pelvis. Stabilisation of the pelvis during the lower limb lowering task, involved steadying of the anterior pelvic rim against the tendency for it to rotate anteriorly as the lower limb was lowered (Kendall & McCreary, 1983). This is an isometric version of the pelvic tilt exercise. Mild to moderate EMG activity in lower Rectus Abdominis and External Oblique and slight activity in upper Rectus Abdominis was seen by Flint and Gudgeon (1965) during supine pelvic tilting with the knees flexed. However, Carman et al., (1972) reported similar activity in upper and lower Rectus Abdominis and External Oblique with slightly less Internal Oblique/Transversus Abdominis activity for a supine pelvic tilt, although the position of the lower limbs was not reported. Examination of the median n-IEMG values in this study showed upper and lower Rectus Abdominis to be more active relative to the subMVIC level than the obliques at each MT level of difficulty. However at Level 4 (bilateral lower limb lowering), there was less difference in activity levels between Rectus

Abdominis and the obliques, in comparison to MT Level 1, 2 and 3 which require single lower limb lowering.

A variation in results for pelvic stabilisation with single or bilateral lower limb lowering was also seen in the relationship between the MT level achieved and the n-IEMG values recorded. For single leg lowering, the n-IEMG values in all abdominal muscles tested tended to increase with the level of test difficulty from Level 1 to Level 3. At Level 4, where simultaneously both lower limbs were lowered, there was a decrease in Rectus Abdominis activity while the activity of the oblique abdominal muscles continued to rise. The increased role of the oblique muscles, and relative decrease of Rectus Abdominis, in pelvic stabilisation during double limb lowering relative to single lower limb lowering may indicate that stabilisation of the pelvis under conditions of double leg lowering is functionally different to single leg lowering.

In summary, there was no relationship between the amount of exercise performed per week and the MT result. The pattern of muscle usage indicated, for this MT for abdominal muscles, that the primary muscle used was Rectus Abdominis although at Level 4, the contribution from the oblique muscles was proportionally increased. For Levels 1 to 3 the electromyographic output of all abdominal muscles tested tended to increase with the

level of test difficulty, the greatest increment being seen between Levels 2 and 3. Level 4 was marked by a decrease in Rectus Abdominis activity while the activity of the oblique abdominal muscles continued to rise.

For this MT there appeared to be a difference in response by the abdominal muscles depending on the level of difficulty. Where the pelvis was to some extent being supported by at least one fixed or non-moving lower limb the abdominal muscles worked with a particular pattern of synergy, increasing the activity level as the difficulty increased. However when there was no support at all, the role of the oblique muscles, particularly External Oblique increased and the Rectus Abdominis decreased.

In conclusion, this study shows that this muscle test was more suitable for assessing abdominal muscle strength than the commonly used subjective double leg lowering test. The MT was an objective test as it was discriminative of muscle strengths in its grades and increased the level of difficulty with each grade for Levels 1 to 3. It was a valid indicator of ability to develop voluntary abdominal muscle tension in Levels 1 to 3, however, Level 4 was more indicative of the oblique muscles abilities and therefore may be considered a distinctly different muscle test.

Part II THE ABILITY OF THE ABDOMINAL MUSCLES TO STABILISE THE PELVIS FOR MATERNAL SUBJECTS

It is assumed that the functional roles of the abdominal muscles during pregnancy are similar to those in the non-pregnant state (Boissonnault & Kotarinos, 1988). These include the role of pelvic stabilisation. However the ability to perform this functional role during pregnancy and the immediate post-birth period is questionable due to changes in the gross structure of the abdominal muscles as shown in Chapter 4. Surprisingly, there has been little work on the function of abdominal muscles during this time. Abdominal muscle strength was manually tested postpartum by Spence (1978), who reported a tendency for pregnancy to reduce the strength of the abdominal muscles.

Thus having validated the MT, it was then used to examine the functional changes in the ability of the abdominal muscles to perform the function of anterior pelvis stabilisation during pregnancy and the immediate post-birth period.

METHODS

Six primigravid subjects as detailed in Appendix IV, participated in the study. Each subject was instructed to perform the MT as outlined in Part I, using each lower limb. The last successfully completed level of difficulty was noted as the MT result.

Muscle test grades were ordinal data (Walker et al., 1987) which would indicate the use of nonparametric statistics in further statistical analysis. However, low subject numbers and missing data due to subject withdrawal on medical grounds or pre-term delivery precluded the use of nonparametric statistical methods. Therefore in consultation with the Director of Statistical Consulting, University of Wollongong (Russell, 1991), no statistical analysis was applied to muscle test data. The presented results and discussion are descriptive.

RESULTS

As shown in Table 6, the MT results for each subject, at the first test session (week 14, 18 or 22 gestation) ranged between Levels 2 and Level 4. From Table 6, it can be seen that 3/6 subjects had decreased ability to stabilise the pelvis by week 26 gestation. At 30 weeks gestation, the MT results ranged from Level 1 to Level 3. Between 30 and 38 weeks gestation, the ability to stabilise the pelvis was found to have diminished in all subjects. The ability to stabilise the pelvis remained diminished in the post-birth period. Post-birth four weeks, the majority of subjects achieved Level 1 and at post-birth eight weeks, only one subject had increased her result to the level of her first test session.

Table 6. Maternal Subjects Muscle Test Results

Subject	1	2	3	4	5	6
<hr/>						
Gestation (weeks)						
14	3		2		2	4
18	3	3	2		3	3
22	3	3	1	3	3	3
26	3	3	1	3	2	3
30	3	3	1	3	2	3
34	*	3	1	3	1	3
38	*	*	*	2	1	2
Post-Birth (weeks)						
4	1	2	1	1	1	1
8	1	3	1	1	1	2

* missing data due to withdrawal on medical advice or pre-term delivery

DISCUSSION

At the first test session, one of six subjects achieved a Level 4 result while all subjects achieved a Level 2 or greater. This proportion of maternal subjects achieving Level 4, was similar to the proportion of non-pregnant subjects who achieved Level 4 in the validation study for the MT as described in Part I. However the proportion of subjects achieving Level 2 or higher was greater in the maternal group of subjects than in the non-pregnant subjects used for the validation study.

The MT results for the maternal subjects from this study showed that as the pregnancy progressed and during the post-birth period there was a trend for the ability to stabilise the pelvis while supine to decrease. In the supine position, the abdominal muscles are under less load from the gravid uterus than in the standing posture. Therefore it follows that when in the erect standing posture where the abdominal muscles are under increased workload due to the effect of gravity on the gravid uterus, the ability to stabilise the anterior pelvis may be further reduced. A possible effect of a decreased ability to stabilise the anterior pelvis would be increased lumbar lordosis in standing. Such an increase in lumbar lordosis during standing as pregnancy

progressed has been previously found by Bullock et al., (1987).

Desanto and Hassid, (1983), suggested the maintenance a posterior pelvic tilt as solution for poor standing posture during pregnancy. Also, Shearer (1981) recommended posterior pelvic tilts held for progressively longer periods to exercise abdominal muscles. The results of the present study indicate these tasks would become progressively more difficult to perform as the pregnancy progressed and remain difficult up to eight weeks post-birth. Further study is warranted to examine the ability of a pregnant woman to perform the posterior pelvic tilt and the effect of performing this exercise while standing.

In summary, the maternal subjects for this study, were similar to non-pregnant subjects in their initial range of anterior pelvis stabilisation abilities. However, the ability to stabilise the pelvis was reduced as the pregnancy progressed, and for the majority of subjects remained low to at least eight weeks post-birth.

CHAPTER 6:

EMG INDICES OF ABDOMINAL MUSCLE FUNCTION

INTRODUCTION

In Chapter 5, qualitative evidence was presented that suggested that abdominal muscle function was compromised by the musculoskeletal changes induced by pregnancy. In this chapter, the investigation of functional changes in abdominal muscles was extended to an analysis of EMG patterns of the Rectus Abdominis and External Oblique during the performance of isometric contractions and four abdominal exercises. This analysis permitted estimations of changes in the relative contributions of the superficial abdominal muscles when performing selected activities.

When an individual muscle contracts the mechanical consequence is to approximate its boney points of attachment, although whether it does so depends upon the tension it is capable of producing balanced against the forces which oppose its shortening (Warwick & Williams, 1973). During pregnancy the tension producing capabilities of the abdominal muscles have been questioned (Blankfield, 1967; Desanto & Hassid, 1983; Gleeson & Pauls, 1988; Shrock et al., 1981) and the gravid uterus is an increasing mass located between the boney points of attachment which opposes apposition of the attachment points. Therefore the ability of the abdominal muscles to function normally is questionable.

The EMG signal of a muscle may be used to indicate muscle tension produced in isometric contractions (Basmajian & DeLuca, 1985) and therefore may be used to assess the functional abilities of the abdominal muscles. The aim of the work in this chapter was to measure the EMG signal level produced by abdominal muscles performing selected activities during pregnancy and the immediate post-birth period. The functional capabilities and inter-relationships between the abdominal muscles were then discussed.

METHODS

Six maternal and ten control subjects participated in the study. Subject profiles are detailed in Appendix IV.

Location of Electrode Sites

The electrode sites were on the right abdomen, overlying the upper and lower Rectus Abdominis and External Oblique. The locations were as described in Chapter 3.

Skinfolds

For the maternal subjects, skinfolds were taken while the subject was supine at three abdominal positions which corresponded to the EMG electrode sites. All skinfolds were taken by the author, using a method similar to that described by Telford et al., (1984, 1988). At each site, the skinfold size was taken after a two second duration of pressure on the skin using skinfold calipers (Eiken Type Skinfold Caliper, Meikosha Co. Ltd). The skin was released and the measure was repeated approximately one minute later. The average of these two measurements was recorded. The skinfolds were orientated in the direction of the muscle fibres beneath them. Therefore the upper and lower Rectus Abdominis

skinfolts were vertical and the External Oblique skinfold was directed inferio-medially.

Using grouped skinfold results, changes in skinfolts over the duration of the study from 14 weeks gestation to eight weeks post-birth, were investigated using a paired Student t-test to examine between test sessions (Gehring, 1978). An ANOVA was also used to determine any significant ($p < 0.05$) changes in skinfold size over the study period (Gehring, 1978).

Background IEMG Signal Activity

For both control and maternal subjects, with the subject supine, relaxed and quietly breathing, two two second background recordings at each electrode site were taken. From each recording 500ms of signal, from 1 sec to 1.5 sec, was chosen for analysis. The sample signal was processed, as outlined in Chapter 3, to calculate IEMG. The calculated average IEMG of the two background samples was used in data analysis.

Changes in background IEMG over time, and differences between control and maternal groups for each electrode, were determined by a repeated measures ANOVA over 18, 22, 26, and 30 weeks gestation for maternal subjects, and test sessions one to four for control subjects using a SPSS-X software package (SPSS-X, 1988).

Functional Appraisal

Both control and maternal subjects were used in the functional appraisal of the abdominal muscles during a sub-maximal voluntary isometric contraction and selected abdominal exercises.

i) Sub-Maximal Voluntary Isometric Contraction (subMVIC)

The supine subject was instructed to isometrically contract her abdominal muscles maximally for two seconds and then relax. Verbal encouragement was given by the author during the contraction. Three trials were recorded, and the subject was allowed rest periods of approximately one minute between each trial.

Using WASP software (Carlyon, 1987), each trial was displayed visually and a 500ms sample for each electrode of the most active EMG signal was chosen. The sample signal was processed as outlined previously in Chapter 3, and the average volts*second for the sample was calculated (IEMG). The mean of three trials of the subMVIC was used in data analysis.

Changes in the subMVIC IEMG over time, and differences between control and maternal groups, for each electrode were determined by a repeated measures ANOVA (SPSS-X, 1988) using test sessions one to four for the control subjects and weeks 18, 22, 26, and 30 for the maternal subjects.

ii) Selected Abdominal Exercises

EMG signal levels were measured during five selected exercises. The activities included an isometric contraction, and the pelvic tilt, curl-up, diagonal curl-up and seated tilt-back exercises. A full description of the abdominal exercises is found in Appendix III. The subjects were asked to perform, to the best of their own level of ability, five trials of each abdominal exercise, with rest periods of approximately one minute between each trial.

During each exercise electronic movement monitoring devices were used. For the pelvic tilt exercise the pressure beneath the lumbar spine was recorded using an electronic sphygmomanometer as previously described in Chapter 5. This pressure reading was used as an indicator of posterior pelvic tilt.

The device used to monitor movement during the curl-up, diagonal curl-up and seated tilt-back exercises was a continuous potentiometer linked to a circular disc. A cord was attached the subject's bra shoulder strap at one end, passed over the circular disc, and attached to a weight of 39.5 gms. The circular disc linked to the continuous potentiometer was rotated by the cord as the subject moved in one direction during the exercise, and in the opposite direction as the subject returned to commencement position, thus causing the potentiometer to

rotate. The potentiometer dc output was passed to an amplifier.

The dc signal from the electronic sphygmomanometer and potentiometer was amplified and recorded simultaneously with the EMG output from the abdominal muscles on a personal computer.

After the test session, for each trial of the abdominal exercises the dc movement signal was displayed. The 'hold phase' of movement was visually determined by the author and a 500ms time period during the hold phase was selected. The simultaneous abdominal muscle EMG signal for the selected time period was used for further analysis.

The sample signal was processed as outlined in Chapter 3, and the average volts*second for the sample was calculated (IEMG). The mean of the results for the five trials for each abdominal exercise were used in data analysis.

To examine the inter-relationship between the abdominal muscles, each muscle relative IEMG (rel-IEMG) was calculated by expressing the IEMG activity of each muscle as a percentage calculated from the sum of the IEMG values of the three muscles as in equation 3 (Viitasalo, 1983).

$$\text{rel-IEMG} = \text{IEMG } m_1 / \text{IEMG } m_1 + \text{IEMG } m_2 + \text{IEMG } m_3 \text{ (Eq.3)}$$

where m = muscle

Changes in the rel-IEMG over time for each electrode were determined by Student t-tests on the differences between test sessions for paired data, and an analysis of variance (Gehring, 1978).

Rating of Performance of Abdominal Exercises

The subject's ability to perform curl-up and diagonal curl-up exercises was rated by the author, using an ordinal scale of one to five as shown below.

Grade 1: unable to attempt the movement

Grade 2: very difficult. The subject was able to raise the head from the plinth but not able to raise the trunk.

Grade 3: difficult. The subject was able to raise the head and scapula partially clear of the plinth.

Grade 4: moderate success. The subject was able to partially perform the exercise but the curl-up was to less than the authors assessment of 45^0 from the horizontal.

Grade 5: successful completion.

The results were pooled and, as the performance rating scale was ordinal, the median and range of the performance ratings were calculated.

RESULTS

Skinfolds

Skinfolds on an abdomen containing a growing foetus proved to be difficult to obtain especially vertical folds over Rectus Abdominis where the skin occasionally could not be grasped clear of the underlying muscle. Where this occurred, no skinfold measure was recorded.

Scatterplots of skinfolds versus time, for each site, are shown in Figure 11, with the means of each test session highlighted. Student t-tests, on the differences between test sessions, found there was no significant ($p < 0.05$) difference in skinfold size between test sessions over upper and lower Rectus Abdominis and External Oblique electrode sites. ANOVA also found no significant ($p < 0.05$) differences in skinfold size for all electrode sites over the period of the study.

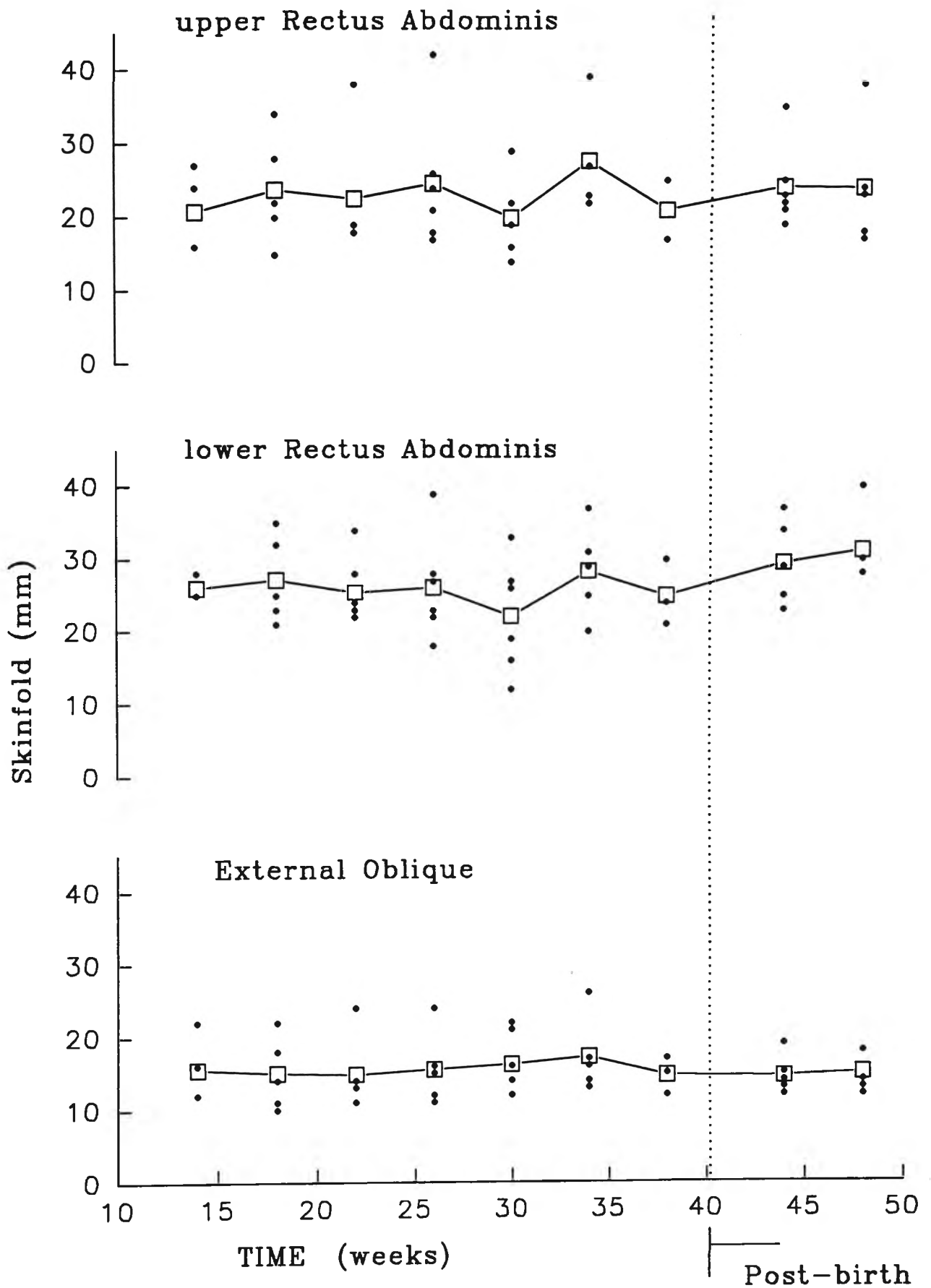


Figure 11. Scatterplot of Skinfold Size versus Time

Background EMG Signal Activity

The background IEMG for upper and lower Rectus Abdominis and External Oblique did not vary significantly ($p < 0.05$) from test session to test session for both the control and maternal subjects. There was also no significant difference ($p < 0.05$) in the background IEMG from control subjects to that of the background signal from the maternal subjects. Figure 12 shows the upper Rectus Abdominis background IEMG signal for both control and maternal groups.

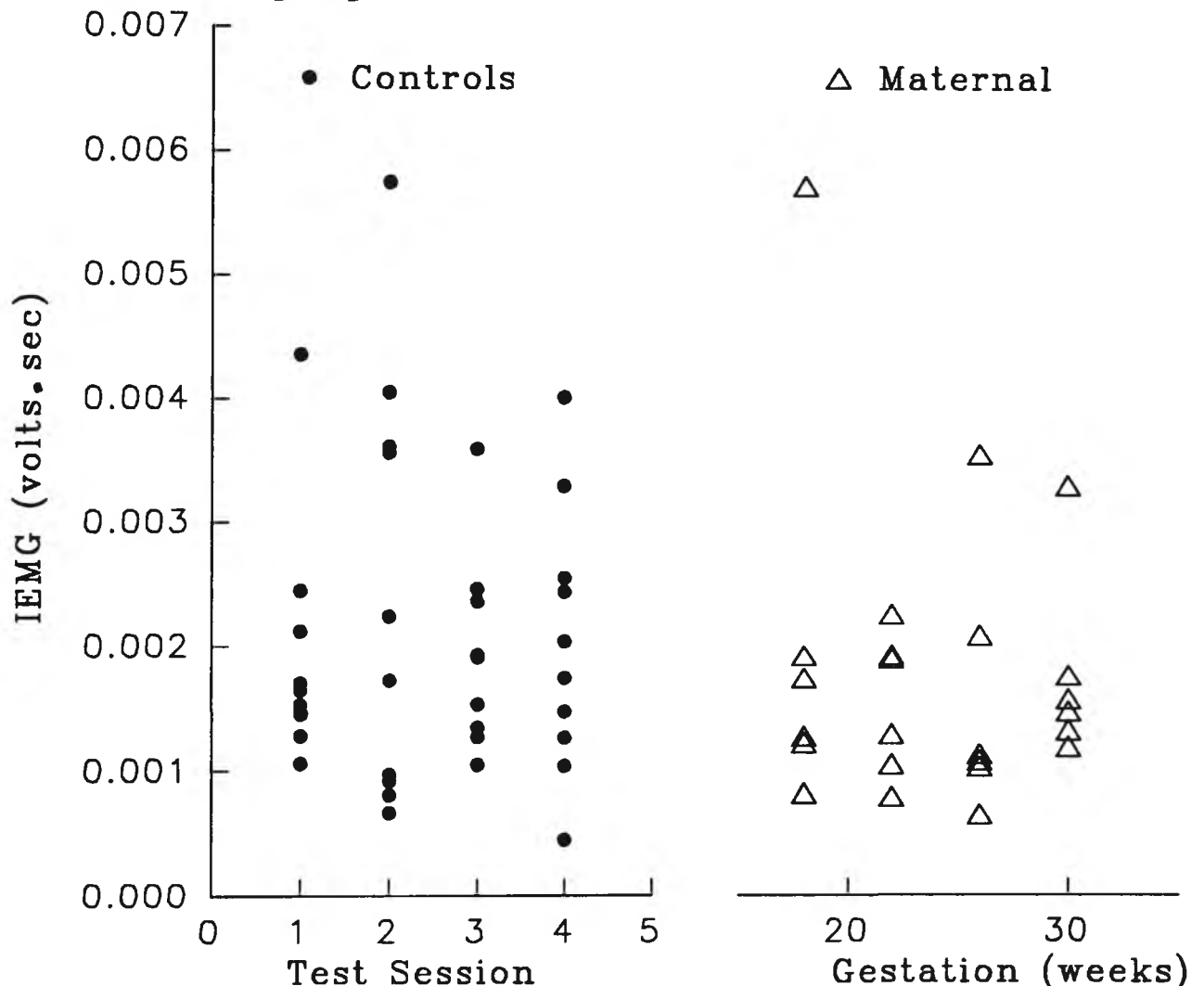


Figure 12. Upper Rectus Abdominis Background IEMG Signal

Functional Appraisal

i) subMVIC

There was no significant difference in subMVIC IEMG signal level between controls and maternal subjects for all muscles tested, and there was also no significant change in subMVIC IEMG over time for upper and lower Rectus Abdominis. For the maternal group External Oblique, however, there was a significant ($p < 0.05$) change over time for weeks 18, 22, 26 and 30. Figure 13 shows a plot of subMVIC control and maternal group data for External Oblique IEMG signal versus time over the

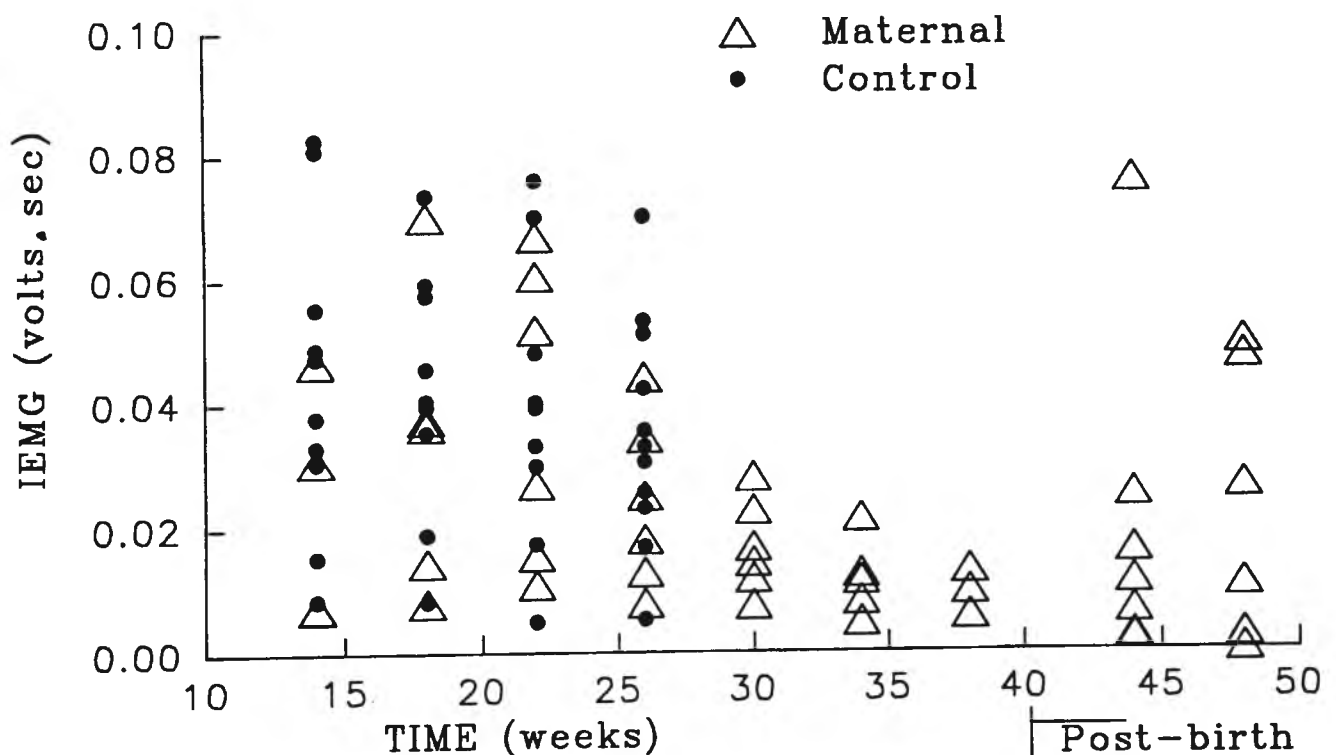


Figure 13. Scatterplot of subMVIC External Oblique IEMG versus Time

complete study period. From Figure 13, it can be seen, the maternal group subMVIC External Oblique IEMG appears to decrease from week 26 gestation to week 38, with an increase seen post-birth. The control group, however did not appear to vary in a constant direction with time.

ii) Selected Abdominal Exercise Activities

a) Control Group:

Figures 14 to 18 show for an isometric contraction, and pelvic tilt, curl-up, diagonal curl-up and seated tilt-back exercises the mean rel-IEMG of upper and lower Rectus Abdominis and External Oblique for the four repeat test sessions. From Figures 14 to 18 it can be seen there was variation in upper and lower Rectus Abdominis and External Oblique rel-IEMG from test to retest. However over the period of the study, this variation was not significant ($p < 0.05$).

Figures 14 and 15 show for the control group, that the External Oblique tended to produce the greatest rel-IEMG during an isometric contraction and the hold phase of the pelvic tilt exercise. During the hold phase of curl-up, diagonal curl-up and seated tilt-back exercises, shown in Figures 16 to 18, upper and lower Rectus Abdominis produced similar rel-IEMG values which were higher than those for External Oblique.

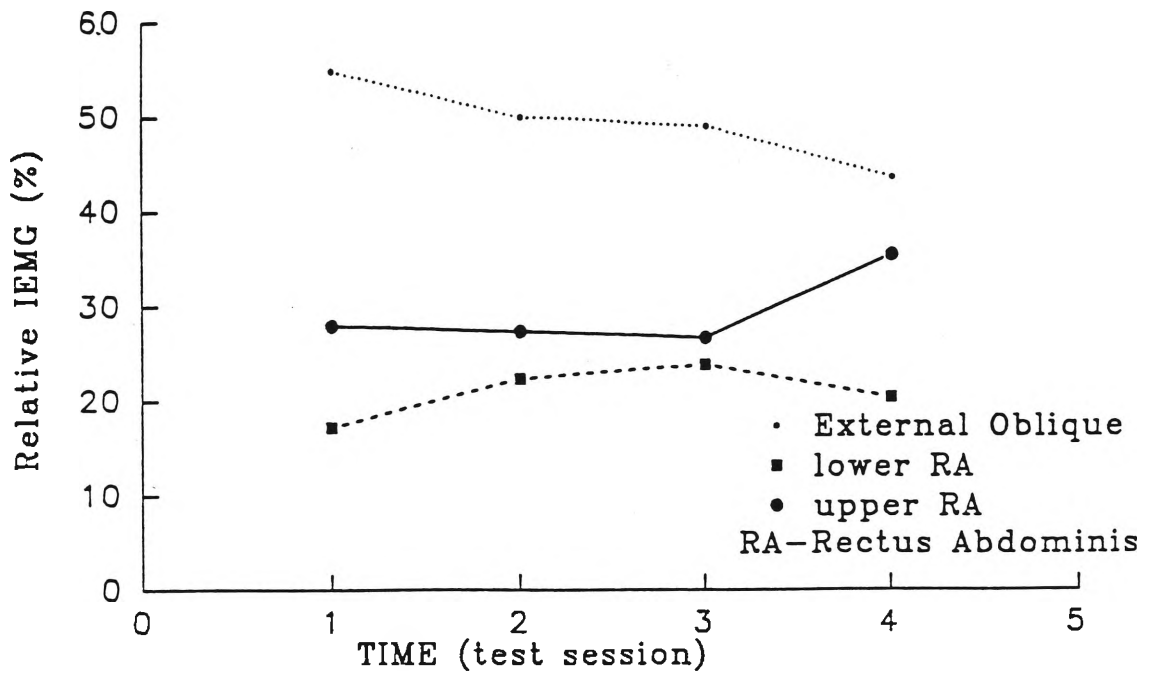


Figure 14. Control Group Mean Rel-IEMG During an Isometric Contraction

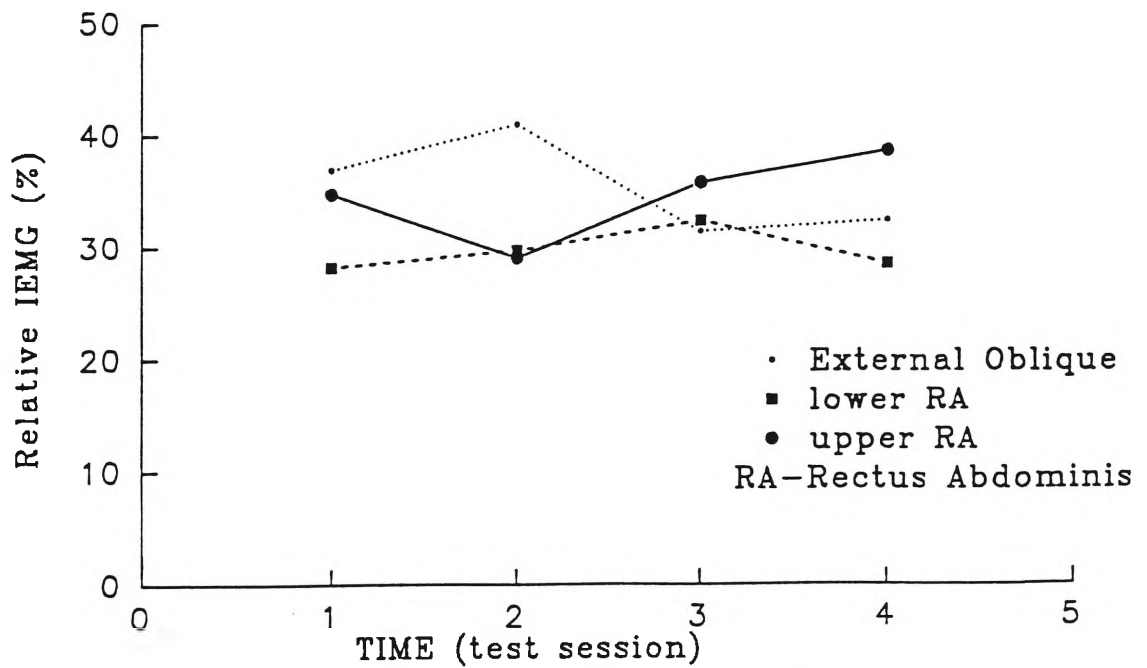


Figure 15. Control Group Mean Rel-IEMG During the Hold Phase of a Pelvic Tilt Exercise.

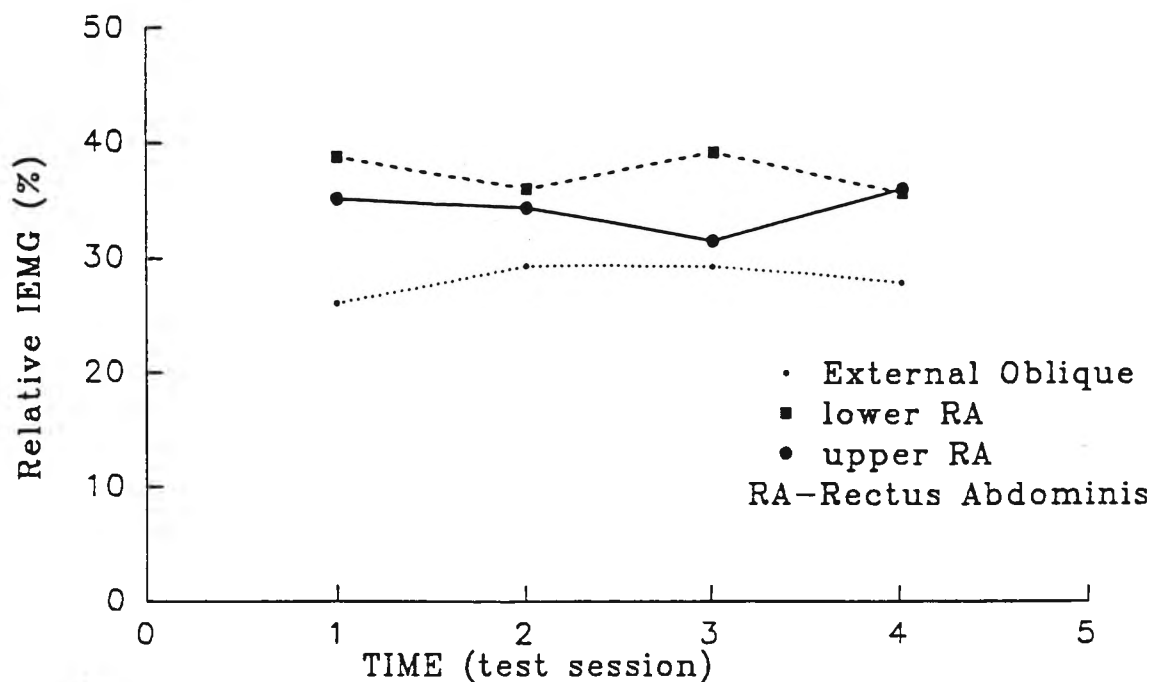


Figure 16. Control Group Mean Rel-IEMG During the Hold Phase of a Curl-up Exercise.

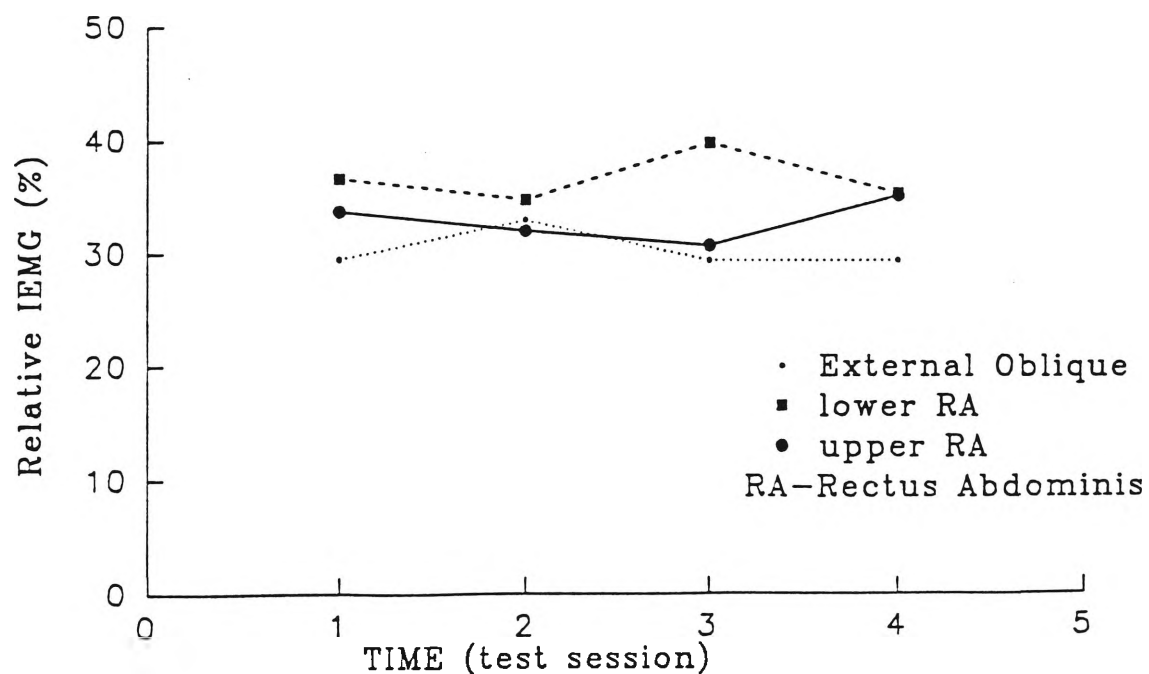


Figure 17. Control Group Mean Rel-IEMG During the Hold Phase of a Diagonal Curl-up Exercise.

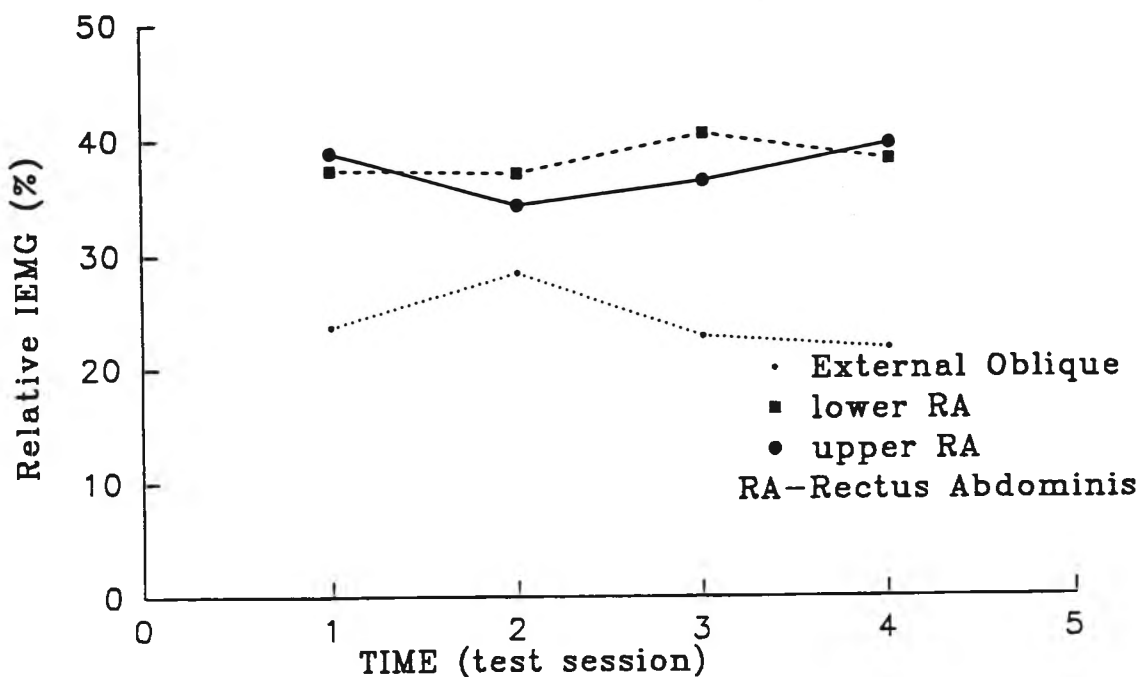


Figure 18. Control Group Mean Rel-IEMG During the Hold Phase of a Seated Tilt-back Exercise.

b) Maternal Group:

Figures 19 to 23 show for an isometric contraction, and pelvic tilt, curl-up, diagonal curl-up and seated tilt-back exercises the rel-IEMG mean value for upper and lower Rectus Abdominis and External Oblique, from 14 weeks gestation to eight weeks post-birth. From Figures 19 to 23 it can be seen there was insignificant variation in rel-IEMG values from test to retest for all muscles tested. This was similar to the control group.

However over the period of the study, there was a tendency for some rel-IEMG values to change. From Figures 19 to 23, it can be seen there was an overall tendency

for increase in the upper Rectus Abdominis rel-IEMG during pregnancy and a trend to decrease during the immediate post-pregnancy period to week 18 to 22 gestation levels, for all selected abdominal exercise activities. These changes in rel-IEMG values were significant ($p < 0.05$) for an isometric contraction, and curl-up, diagonal curl-up and seated tilt-back exercises, over the study period.

Figures 19 to 23, also show a trend for a decrease in the rel-IEMG External Oblique during pregnancy with an increase seen for post-birth to week 18/22 gestation levels, for all selected abdominal exercise activities. These changes were significant ($p < 0.05$) during the study period for the curl-up and diagonal curl-up exercises.

Lower Rectus Abdominis rel-IEMG also tended to decrease during pregnancy and increase post-birth to week 18/22 gestation levels as seen in Figures 19, 21 to 23. However, for the pelvic tilt exercise, shown in Figure 20 there was no apparent change throughout the pregnancy and immediate post-birth period. The lower Rectus Abdominis rel-IEMG changed significantly ($p < 0.05$) over the study period for curl-up, diagonal curl-up and seated tilt-back exercises.

During weeks 14 and 18 gestation and throughout post-birth, Figure 19 and 20 show the External Oblique, as in the control group, tended to produce the greatest

rel-IEMG during an isometric contraction and the hold phase of the pelvic tilt exercise. However for the same exercises, during late pregnancy the greatest rel-IEMG was produced by upper Rectus Abdominis. From Figures 21 to 23, during the hold phase of curl-up, diagonal curl-up, and seated tilt-back exercises in week 14 and 18 gestation and throughout the post-birth period, upper or lower Rectus Abdominis produced the greatest rel-IEMG, again similar to the control group. However, again during late pregnancy the upper Rectus Abdominis became predominate in these exercises.

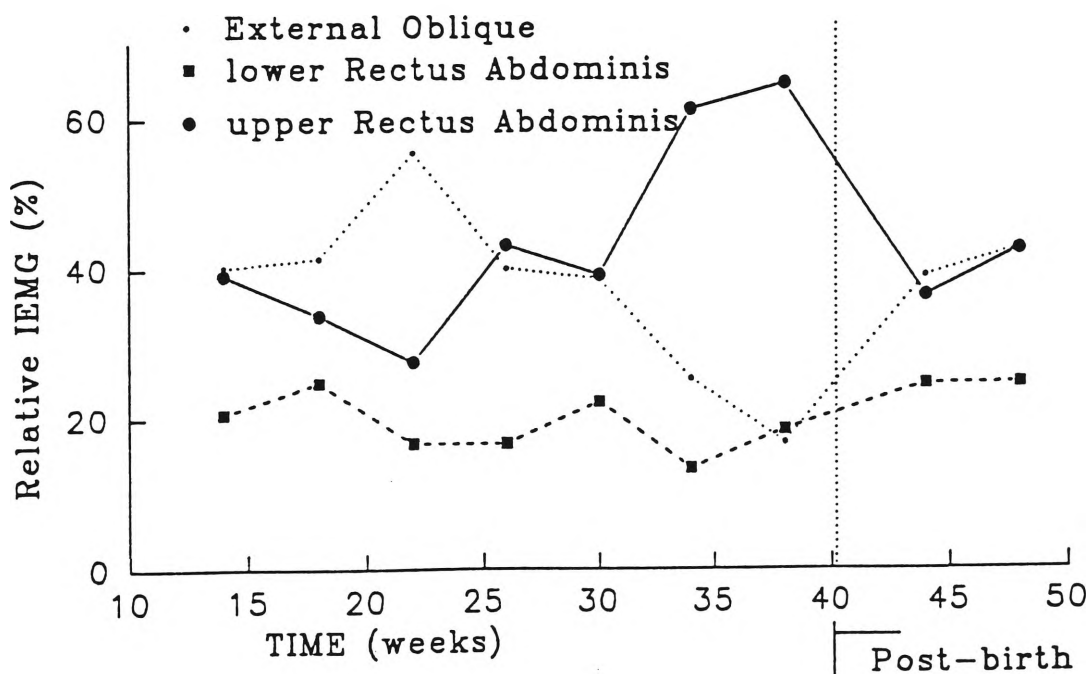


Figure 19. Maternal Group Mean Rel-IEMG During an Isometric Contraction.

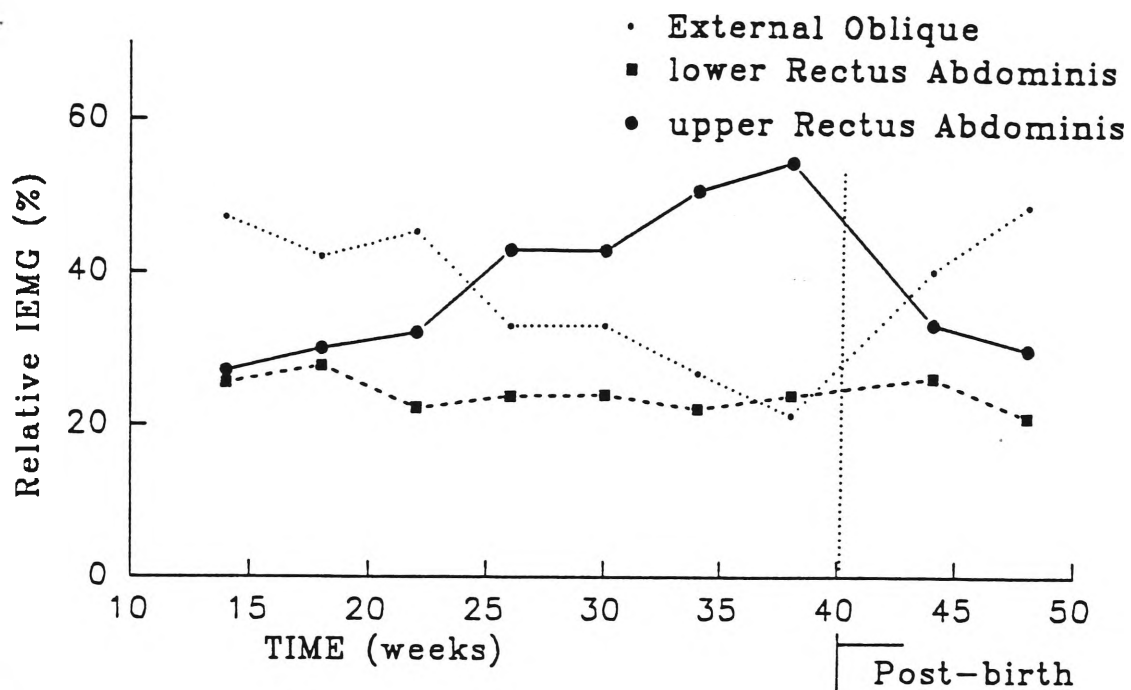


Figure 20. Maternal Group Mean Rel-IEMG During the Hold Phase of a Pelvic Tilt Exercise.

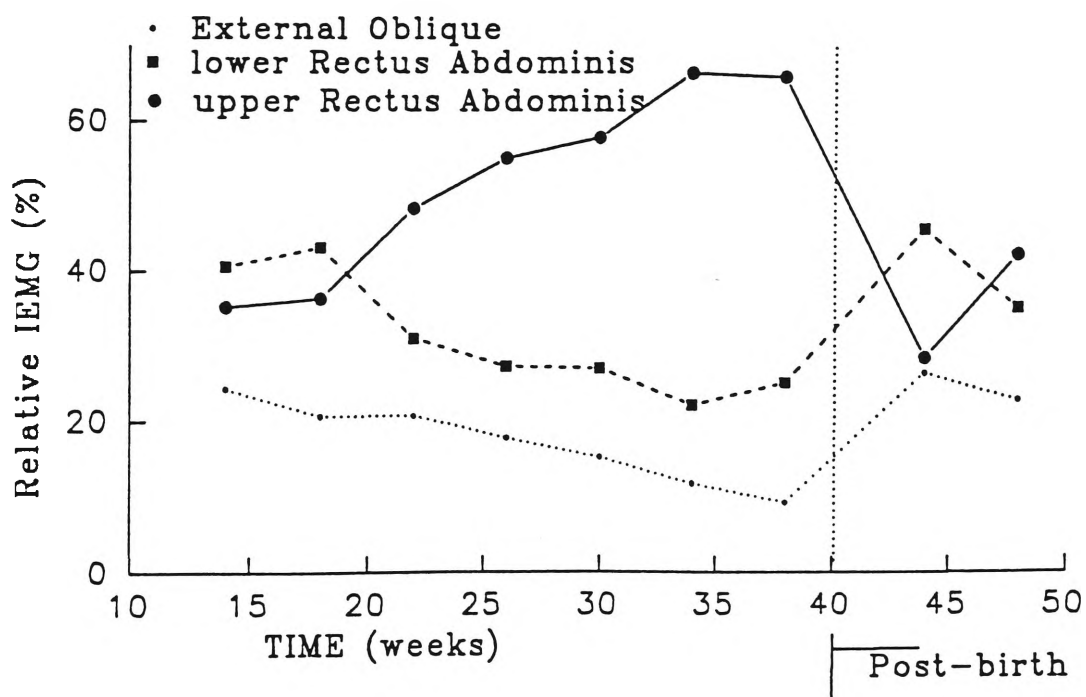


Figure 21. Maternal Group Mean Rel-IEMG During the Hold Phase of a Curl-up Exercise.

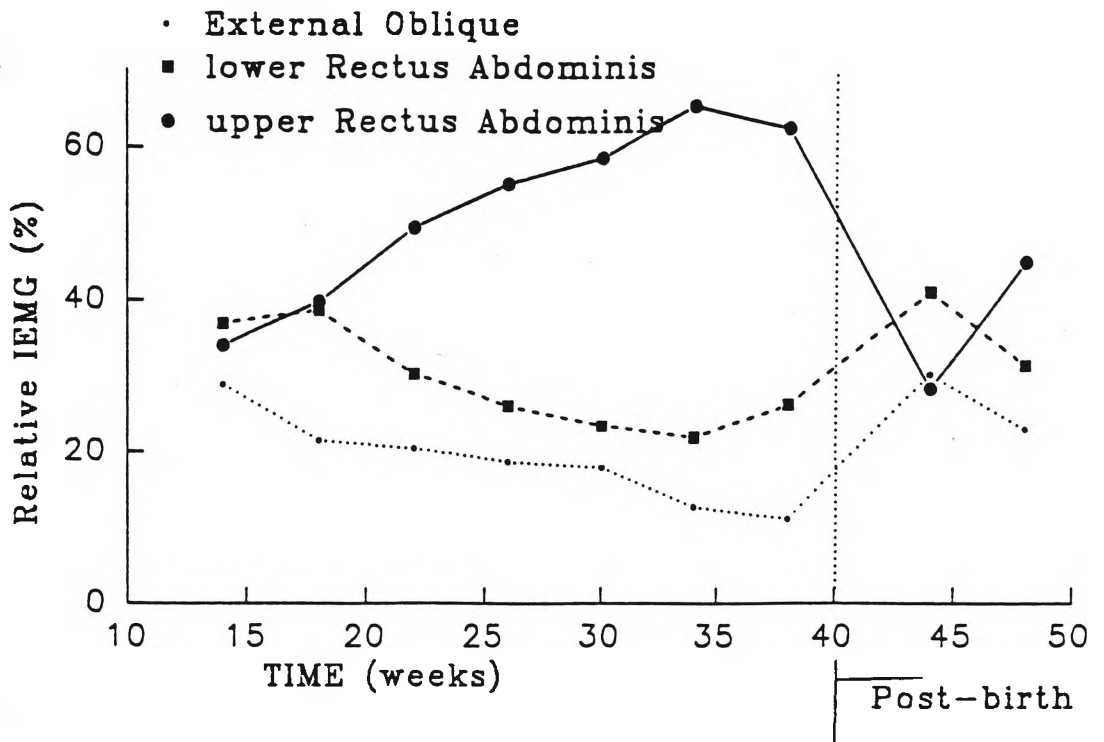


Figure 22. Maternal Group Mean Rel-IEMG During the Hold Phase of a Diagonal Curl-up Exercise.

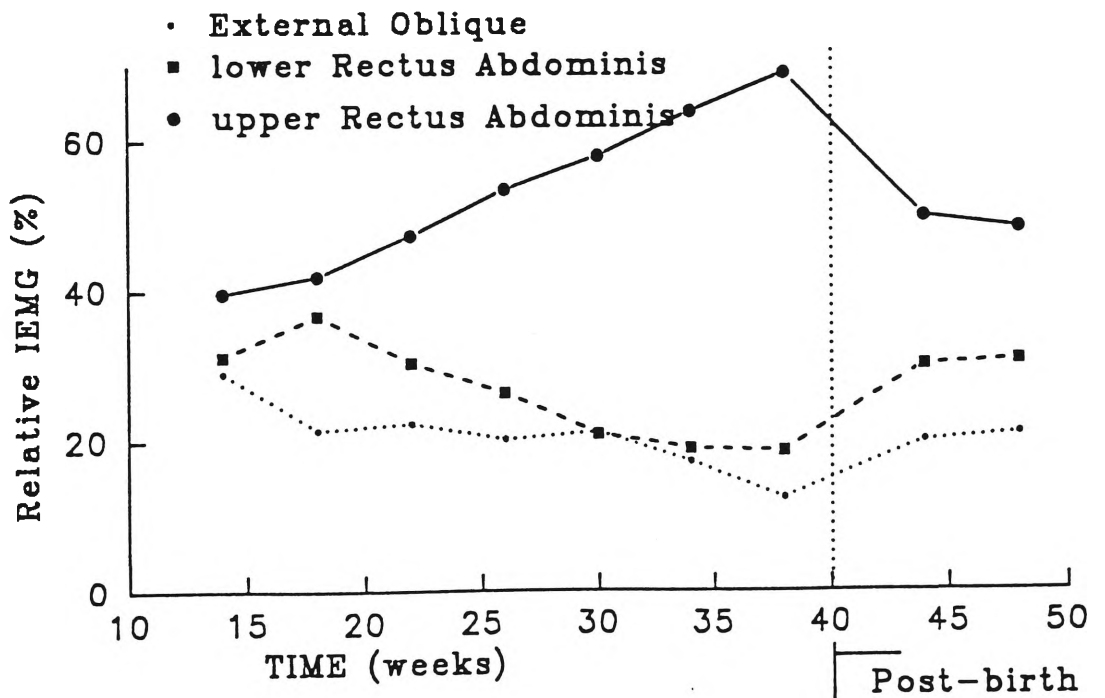


Figure 23. Maternal Group Mean Rel-IEMG During the Hold Phase of a Seated Tilt-back Exercise.

Rating of Performance of Curl-up and Diagonal Curl-up

Exercises

The median and range of performance rating for curl-up and diagonal curl-up exercises are given in Table 7.

Table 7. Median and Range of Curl-up & Diagonal Curl-up Performance Rating

	Curl-up			Diagonal Curl-up	
	N	M	R	M	R
Gestation (weeks)					
14	4	5	(5)	5	(5)
18	5	5	(5)	5	(5)
22	6	5	(4-5)	5	(4-5)
26	6	4	(4)	4	(4)
30	6	3.5	(3-4)	4	(3-4)
34	5	3	(2-3)	4	(3-4)
38	3	3	(2-3)	3	(3-4)
Post-birth (weeks)					
4	6	3.5	(3-4)	4	(4-5)
8	6	4	(3-5)	4	(4-5)

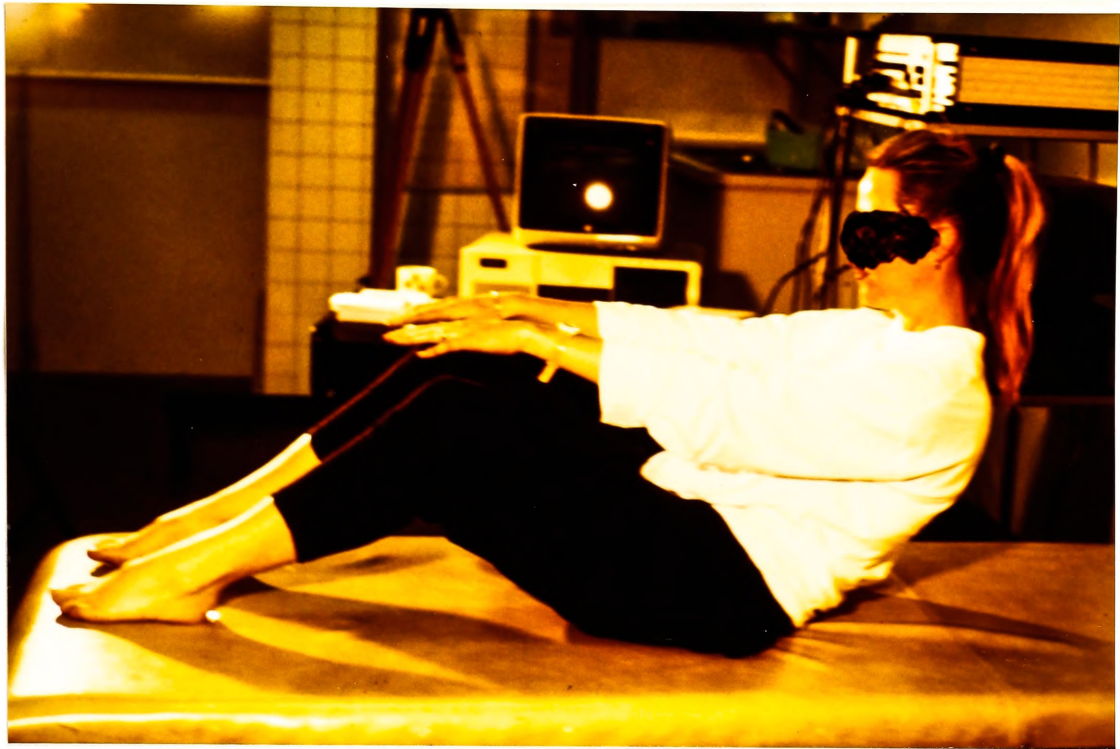
N Number of Subjects

M Median abdominal exercise performance rating

R Range of abdominal exercise performance rating

The maternal subjects were able to successfully perform a Curl-up and Diagonal Curl-up from 14 to 22 weeks gestation, as seen in Figure 24 A. The curl-up exercise median performance rating after 22 weeks gestation decreased from successful to difficult at 38 weeks gestation, as seen in Figure 24 B. The median

performance rating for the curl-up exercise was increased to moderate success by eight weeks post-birth, a similar median rating to that at 26 weeks gestation. The performance rating of the diagonal curl-up exercise followed a similar pattern to that of the curl-up exercise during pregnancy and the post-birth period. The median performance rating decreased at 26 weeks gestation, but then plateaued until 34 weeks gestation, before continuing to decrease to a median performance rating of difficult at 38 weeks gestation. Post-birth, the median performance rating of the diagonal curl-up exercise was increased to moderate success. Again as found for the Curl-up exercise, this was a similar median and range of performance rating to that shown at 26 weeks gestation.



A.



B.

Figure 24. Performance of Curl-up at A. 18 Weeks, and
B. 38 Weeks Gestation.

DISCUSSION

Skinfolds

During pregnancy, there is an increase in adipose tissue particularly during the first 20 weeks gestation (Gorski, 1985; Zaidise et al., 1986), although it is unknown how this increase is distributed throughout the body. For electromyography, the amount of tissue the EMG signal must pass through before reaching the electrode will affect the recorded signal (Basmajian & De Luca, 1985). It is therefore necessary to examine the amount of subcutaneous adipose tissue beneath each electrode before conclusions may be made about any changes seen in the EMG signal. The results from the present study indicate there was no significant ($p < 0.05$) increase in subcutaneous adipose tissue over upper and lower Rectus Abdominis and External Oblique from 14 weeks gestation to eight weeks post-birth. Therefore any significant changes in IEMG signal level are not due to additional tissue impedance.

Background EMG Signal Level

The background IEMG signal was similar in both control and maternal groups and additionally there was no significant change ($p < 0.05$) in these signal levels over repeated test sessions. Therefore the potential sources of additional background IEMG signal during pregnancy,

such as the uterine muscle, foetal electrocardiograph and foetal skeletal muscle would not be expected to significantly alter the abdominal muscle IEMG signal level.

Functional Appraisal

i) subMVIC

The control group subMVIC IEMG values for upper and lower Rectus Abdominis and External Oblique did not vary significantly from test to retest. This was an expected result as previous studies have shown satisfactory reproducibility for sub-maximal and maximal isometric contraction IEMG values (Komi & Buskirk, 1970; Viitasalo & Komi, 1975; Yang & Winter, 1983). However for the maternal group, examination of the abdominal muscles IEMG during a subMVIC over repeated test sessions revealed a tendency to decrease in External Oblique IEMG as pregnancy progressed. Therefore, it was not valid to use the subMVIC IEMG as a standard signal. In order to investigate the change in the functional relationship between the abdominal muscles over repeated test sessions, rel-IEMG was calculated instead (Viitasalo, 1983).

ii) Abdominal Muscle Inter-relationship

In the present study the maternal subjects EMG results appeared to be divided into three phases, early pregnancy (weeks 14 and 18 gestation), late pregnancy and the post-birth period. The relationship between rel-IEMG values for upper and lower Rectus Abdominis and the External Oblique were similar in both control and maternal group for early pregnancy and throughout post-birth, when the same selected activity was compared.

Previous studies have examined the abdominal muscles individually and determined their activity during the selected activities examined during this study. For an isometric contraction, External Oblique tended to produce the greatest rel-IEMG values for the control, and maternal subjects in early pregnancy and post-birth. Flint and Gudgeon (1965) reported, however, for an isometric abdominal muscle contraction in non-pregnant subjects, higher absolute EMG signal activity in lower Rectus Abdominis than in External Oblique.

During the hold phase of the pelvic tilt exercise the present study found the External Oblique produced the greatest rel-IEMG values in the control, and maternal subjects in early pregnancy and post-birth. Partridge and Walters (1959), and Carman et al., (1972) also reported External Oblique as having the highest absolute EMG signal activity during a supine pelvic tilt exercise for

non-pregnant subjects. However Flint and Gudgeall (1965) reported lower Rectus Abdominis absolute EMG signal activity to be the greatest during a pelvic tilt exercise.

During the hold phase of curl-up and diagonal curl-up exercises for the control, and maternal subjects in early pregnancy and post-birth in the present study, upper or lower Rectus Abdominis produced similar rel-IEMG values which were higher than those for External Oblique. Partridge and Walters (1959) and Booth et al., (1980) however, reported for non-pregnant subjects performing a trunk curl and trunk curl with a twist, External Oblique and Rectus Abdominis produced similar amounts of absolute EMG activity.

For all selected activities the control group showed no significant change in upper and lower Rectus Abdominis, and External Oblique rel-IEMG values from test to retest. However for the maternal group, during late pregnancy the upper Rectus Abdominis rel-IEMG tended to increase and the rel-IEMG for External Oblique decreased in comparison to the early pregnancy results in all selected activities. Post-birth the rel-IEMG values from upper Rectus Abdominis and External Oblique returned to approximately week 18 to 22 gestation levels. Booth et al., (1980) also found during late pregnancy the absolute contributions from External Oblique and Rectus Abdominis

altered during the performance of a curl-up exercise. They reported Rectus Abdominis absolute EMG signal level during late pregnancy increased and External Oblique activity decreased relative to the activity levels seen in non-pregnancy and post-birth (Booth et al., 1980). However Booth et al., (1980) reported post-birth activity levels similar to non-pregnant levels. This difference in post-birth results reported by Booth et al., (1980) in comparison to the present study may be due to the simpler three levels of EMG activity classification used as against the more specific percentages of total IEMG used in this study.

As discussed above, there was little difference between the control group, and the early pregnancy maternal group results for upper and lower Rectus Abdominis and External Oblique rel-IEMG values during all selected activities. Thus the inter-relationship between the abdominal muscles tended to be similar in early pregnancy to abdominal muscle inter-relationships in non-pregnant subjects for the selected activities of this study. However the abdominal muscle inter-relationship altered during late pregnancy. The upper Rectus Abdominis rel-IEMG increased and External Oblique rel-IEMG values decreased in comparison to the activity levels seen in early pregnancy. Also lower Rectus Abdominis tended to decrease or remain static in comparison to the activity

levels seen in early pregnancy. Post-birth the rel-IEMG values returned to approximately week 18 to 22 gestation levels.

Rating of Performance of Curl-up and Diagonal Curl-up Exercises

In the present study, at 26 weeks gestation the ability to perform a curl-up type abdominal exercise decreased. This decline continued to 38 weeks gestation, at which time no subjects were successful in completing curl-up or diagonal curl-up exercises. However, Fast et al., (1990) found in 22 out of 164 subjects at mean 38 weeks gestation, that they could successfully complete a hook lying sit-up with their hands clasped behind their head. The higher number of successful subjects in the Fast et al., (1990), study may be due to the use of a less extensive curl-up movement than that used in this study. Also, the abdominal exercises were performed for the present study slowly and in a controlled manner. The speed of movement used by Fast et al., (1990) was not stated and a fast movement speed may have been used by the subject to successfully complete the sit-up.

The rating of performance of curl-up and diagonal curl-up abdominal exercises was improved post-birth. In the present study, 3/6 of subjects were successful or moderately successful in producing the curl-up exercise

while additionally all subjects were successful or moderately successful for the diagonal curl-up exercise. This improvement post-birth supports previous findings by Spence, (1978), who found that in six weeks post-birth subjects, 80% could complete a curl-up exercise similar to that used in the present study.

Effect of Altered Movement Performance on EMG

As noted above the performance of curl-up and diagonal curl-up exercises became increasingly difficult as the pregnancy progressed. At late pregnancy, a curl-up exercise would have more accurately been described as a supine head raise for the majority of subjects, as seen in Figure 24 B. For a supine head raise Floyd and Silver (1950) and Carman et al., (1972) reported high absolute Rectus Abdominis EMG signal activity and lower absolute External Oblique activity which supports the results of this study. Therefore the observed changes in abdominal muscle inter-relationships during late pregnancy may reflect an altered movement due to obstruction by the gravid uterus to approximation of the anterior thoracic cage to the pelvis, rather than a change in muscle tension producing capability.

Summary

The upper and lower Rectus Abdominis and External Oblique muscle inter-relationships in control subjects did not tend to alter over the study period when producing an isometric contraction and pelvic tilt, curl-up, diagonal curl-up and seated tilt-back exercises. For the same selected activities the rel-IEMG values were similar in both control and early pregnancy maternal groups. However for the maternal group, during late pregnancy the rel-IEMG of upper Rectus Abdominis tended to increase and External Oblique decreased, while the activity of lower Rectus Abdominis tended to decrease or remain static, when compared to the early pregnancy results in all selected movement activities. Therefore the inter-relationship between the abdominal muscles was altered in late pregnancy. Post-birth for all abdominal muscles tested the rel-IEMG values returned to approximately week 18 to 22 gestation abdominal muscle inter-relationships.

The control group showed no significant change in IEMG values during a subMVIC contraction. Maternal subjects also showed no change for upper and lower Rectus Abdominis. However, External Oblique subMVIC IEMG tended to decrease as pregnancy progressed and increased post-birth.

There was no significant increases in background IEMG signal or subcutaneous adipose tissue during pregnancy and the immediate post-birth period. The changes in abdominal muscle inter-relationships and External Oblique subMVIC IEMG during pregnancy and the immediate post-birth period, as discussed above, were therefore not thought to be due to altered EMG signal from increased background signal or increased tissue impedance. However, the observed alterations in abdominal muscle inter-relationships may be a reflection of an altered movement rather than a change in muscle physiological capability.

CHAPTER 7:

GENERAL DISCUSSION

The aim of this study was to investigate structural and functional changes to the abdominal muscles during pregnancy and the immediate post-birth period. This longitudinal study utilised three dimensional photographic, electromyographic and muscle test techniques to investigate primigravid subjects with a single foetus.

As discussed previously in Chapter 2, in order to accommodate the increased dimensions of the uterus throughout pregnancy, the antero-lateral dimensions of the abdomen increase. This is thought to be achieved by several means. The transverse and antero-posterior diameters of the inferior thoracic aperture are increased (Gilroy et al., 1988), thus increasing the circumference of the superior abdomen and altering the relative position of the ribs to the pelvis. The width of the linea alba (Boissonnault & Blaschak, 1988) and the distance traversed by the abdominal muscles between their attachment points (Fast et al., 1990) is also increased. However, there is a paucity of quantitative dimensional data in relation to the above changes and in particular for changes in the gross structure of the abdominal muscles. Therefore, the first aim of this study was to quantify the gross structural changes in a representative abdominal muscle, the Rectus Abdominis, during pregnancy and the immediate post-birth period.

Gross Structure of Rectus Abdominis

The results of this study showed that the gross structure of the Rectus Abdominis was altered during pregnancy. Recti separation and angles of insertions of the Rectus Abdominis were significantly ($p < 0.05$) altered between week 18 to 30 with further significant change in angles of insertion and Recti separation above and at umbilicus between 30 to 38 weeks. In addition, Rectus Abdominis length increased significantly ($p < 0.05$) between week 14 to week 38. Therefore the results of this study showed that by 38 weeks gestation, the Rectus Abdominis had altered from its initial, predominantly vertical, orientation. The Rectus Abdominis deviates first in an antero-lateral direction then in a postero-medial direction as it travels distally, in order to pass around the abdomen rather than to lie in the midline. It is of interest to note that in a supine position at 38 weeks gestation, where the gravid uterus under the influence of gravity is resting against the vertebral column, the mean Rectus Abdominis medial edge length had increased by approximately five centimetres. In standing however it is the view of the author, where the gravid uterus under the influence of gravity is resting against the anterior abdominal wall, a greater increase in muscle length may be seen at 38 weeks gestation.

During the post-birth period, the Recti separation observed during pregnancy was shown to be reversing, although normal muscle position within the abdominal wall was not completely restored by eight weeks post-birth. Post-birth Rectus Abdominis muscle length was not determined as discussed in Chapter 4. As a consequence, the angles of insertion also could not be determined post-birth. However as Recti separation results in an altered angle of insertion in the coronal plane, the presence of post-birth Recti separation is indicative of a continued alteration in coronal plane angle of insertion during the post-birth period.

As discussed earlier in Chapter 4, the increase in Rectus Abdominis length, although significant, may not necessarily reduce the tension produced by the muscle. However the alterations in the angle of insertion in both the sagittal and coronal planes would mean that the muscle's line of action was altered at both its superior and inferior attachment points. This may result in a reduced moment arm length and therefore reduced torque production by the Rectus Abdominis. Thus any functional deficits exhibited by the abdominal muscles during pregnancy and the immediate post-birth period may be biomechanical in nature rather than due to a loss in tension generation due to physiological deficits.

If the gross structure of the abdominal muscles was altered so that muscle torque production was reduced then it follows that these structural changes may be reflected in abdominal muscle functional deficits. However, at this time, there is a paucity of knowledge relative to either the EMG output or manual testing of abdominal muscle function during pregnancy (Boissonnault & Kotarinos, 1988). Thus, the second aim of this study was to investigate the functional capabilities of the abdominal muscles during pregnancy and the immediate post-birth period.

The abdominal muscle functions examined by the present study included pelvic stabilisation and selected trunk movements. The investigative techniques included a muscle test and EMG collection while performing isometric contractions and posterior pelvic tilt, curl-up, diagonal curl-up, and seated tilt-back exercises. The exercises were selected from the recommended abdominal exercises suggested in Chapter 2, Part F.

Stabilisation of the Anterior Pelvis

The functional capability of the abdominal muscles to stabilise the anterior pelvis was examined by a muscle test (Hunt & Henley, 1989). The results indicated that the maternal subjects as a group, at their first test session, were similar in their ability to stabilise the

anterior pelvis to a larger group of non-pregnant subjects used in the muscle test validation. As the pregnancy progressed the abdominal muscles ability to stabilise the pelvis decreased. For the majority of subjects the ability to stabilise the pelvis remained compromised up to eight weeks post-birth.

The correct performance of abdominal exercise requires stabilisation of the pelvis to reduce the potential for lower back injury (Booth et al., 1980; Noble, 1982). Since the ability to stabilise the pelvis was reduced in late pregnancy and post-birth, caution must be used when performing abdominal exercises at these times. Also, when an abdominal exercise is difficult to perform, as was seen for the curl-up and diagonal curl-up in late pregnancy, correct performance techniques may not be followed by the subject. Therefore close supervision of the maternal subject is warranted to minimise the potential for lower back injury.

Ability to Perform Curl-up Type Exercises

The performance rating of curl-up type abdominal exercises decreased as the pregnancy progressed although it was improved post-birth. However, the successful performance of an abdominal exercise does not indicate that the exercise was performed solely by the abdominal muscles. Hip flexors, such as Iliacus, have been found to

be used during the performance of curl-up and diagonal curl-up exercises as the trunk flexed from 45° to 90° and extended from 90° to 45° (Flint, 1965). Therefore, since the ability to stabilise the anterior pelvis (a task performed by the abdominal muscles) was decreased late pregnancy and remained low post-birth, it was possible that the increased post-birth performance rating of curl-up and diagonal curl-up exercises was due to the increased participation of other muscles such as Iliacus. Further research is warranted to establish the role of hip flexors in abdominal exercises during pregnancy and post-birth.

EMG During Pregnancy and the Post-Birth Period

As discussed earlier in Chapter 2, EMG signals are impeded by biological tissues and may be degraded by unwanted electrical activity (Basmajian & DeLuca, 1985). Although it is known that during pregnancy an increase in adipose tissues contributes to maternal weight gain (Zaidise et al., 1986), the distribution of this adipose tissue throughout the body is unknown. Background noise from sources such as foetal heart and uterine muscle may also alter during pregnancy. Therefore the potential effects of increased subcutaneous adipose tissue and bioelectric noise on the EMG signal were assessed during pregnancy and the post-birth period. The results showed,

for the abdominal sites used, that there were no significant increases in background noise or subcutaneous adipose tissue during pregnancy and the immediate post-birth period. Thus any variations in EMG signal level throughout the study were not thought to be due to increased background noise signal or increased tissue impedance.

EMG of an Isometric Contraction

Normalisation of EMG is used to permit the comparison of EMG signals both between muscles and different subjects (Echternach, 1985). For this procedure, the EMG signal may be expressed as a percentage of a standard signal as represented by the subMVIC. Examination of the control group subMVIC IEMG revealed that there was no significant differences seen over the period of the study. However, for the maternal subjects, although there was no significant change in IEMG for upper and lower Rectus Abdominis between 18 to 30 weeks gestation, there was a significant ($p < 0.05$) decrease in External Oblique subMVIC IEMG. Therefore, the subMVIC IEMG could not be used as a standard signal.

The changes in IEMG signal produced by the External Oblique during an isometric contraction between weeks 18 to 30 gestation could possibly be caused by a number of factors. Firstly, the gross structure of the muscle was

probably altered as pregnancy progressed. In the present study, the mean Rectus Abdominis length was found to be increased by 15 % over a 14 week period, although External Oblique length and timing of changes as pregnancy progressed is unknown. Changes of length over short periods of time may stretch the muscle and lead to decreased tension production as defined by muscle length-tension relationships (Kreighbaum & Barthels, 1985). Also a stretched muscle produces lower EMG activity (Viitasalo & Komi, 1975). If External Oblique was subject to relatively short term stretch then decreased EMG activity may possibly be seen.

Secondly, a Japanese study found a decreased EMG output in External Oblique as pregnancy progressed (Takano, 1956). This was thought to be possibly due to the effects of pregnancy hormones (Kawakami, 1954 & 1955) although the relationship between the hormones and skeletal muscle function was undefined. There has been no recent work to validate these findings although other hormones have been noted to affect skeletal muscles (Lalatta Costerbosa et al., 1988). Further work to quantify the gross structural changes to External Oblique and the effect of hormones on the skeletal muscles during pregnancy are warranted to further investigate the decreased IEMG found.

Functional Inter-relationships between the Abdominal Muscles

As normalisation of the EMG signal was not possible the direct comparison of EMG signal levels between the abdominal muscles was not viable. However, the functional inter-relationship between the abdominal muscles was examined by the calculation of rel-IEMG (Viitasalo, 1983) for activities such as an isometric contraction, and the 'hold phase' of posterior pelvic tilt, curl-up, diagonal curl-up and seated tilt-back exercises.

The inter-relationship between the abdominal muscles for each activity did not alter over the study period in the control group subjects. For the same activities the abdominal muscle inter-relationships were similar in both control and maternal groups in early pregnancy. However in the maternal group, during late pregnancy the muscle inter-relationship altered as shown by the increase in rel-IEMG value of upper Rectus Abdominis with a simultaneous decrease in External Oblique. Post-birth the rel-IEMG for the abdominal muscles returned to approximately week 18 to 22 gestation levels.

The altered abdominal muscle inter-relationship seen in late pregnancy and not completely resolved by eight weeks post-birth may be due to several factors. Firstly, the observed changes may be a reflection of an altered movement rather than a change in muscle physiological

capability. As discussed in Chapter 6, the curl-up type movement at 38 weeks gestation resembled a head raise movement, and the EMG pattern recorded was similar to previous authors' results (Carman et al., 1972; Floyd & Silver, 1950) for EMG during a head raise.

Secondly, the gross structure of all the abdominal muscles was possibly altered as pregnancy progressed. This would alter, as discussed for Rectus Abdominis in Chapter 4, the torque producing and therefore functional capabilities of the abdominal muscles. If the functional capabilities of lower Rectus Abdominis and External Oblique were reduced relative to upper Rectus Abdominis, due to gross structural changes as pregnancy progressed, there would be a need for greater torque and therefore tension to be produced by upper Rectus Abdominis to try and achieve the selected activity. This factor could result in altered muscle inter-relationships.

Thirdly, the present study found that the increase in total medial edge length of Rectus Abdominis was 115% of the length recorded at week 14 gestation and this increase was achieved over a period of 14 weeks. It is unknown whether this increase was the result of increased length of muscle and/or connective tissue and also whether the increase in length was spread evenly over the entire length of the muscle. Further work on the effect

of pregnancy on connective and muscle tissue is needed to answer this question.

Time Relationship Between Structural and Functional Changes

In the present study, there appeared to be a time correlation between abdominal muscle structural and functional changes. Significant ($p < 0.05$) changes in Rectus Abdominis separation and angles of insertion were seen by 30 weeks gestation. At this time the maternal subjects ability to perform curl-up and diagonal curl-up exercises had began to decrease, and for 3/6 maternal subjects a reduced ability to stabilise the anterior pelvis was also seen. Further changes in separation and angles of insertion were seen as the pregnancy progressed to 38 weeks gestation, and the Rectus Abdominis length was also significantly increased by week 38. For those subjects who reached 38 weeks gestation, a reduction in the ability to stabilise the pelvis, and further reductions in the ability to perform curl-up type abdominal exercises, was seen within this time. Also the abdominal muscle inter-relationship, as determined by rel-IEMG, was altered during late pregnancy in comparison to early pregnancy. Thus the gross structural alterations seen in Rectus Abdominis during pregnancy which may

result in reduced torque production, were paralleled in time by reduced abdominal muscle functional capabilities.

Post-birth, the separation of Rectus Abdominis returned to week 22 to 26 levels, although length and therefore the angles of insertion were not able to be measured. The ability to perform curl-up type exercises returned to week 26 levels and abdominal muscle rel-IEMG returned to week 18 to 22 levels. However, the ability to stabilise the pelvis was further reduced and remained low at eight weeks post-birth. The incomplete resolution of functional deficits and further decrements in the ability to stabilise the pelvis seen post-birth, indicate that the Rectus Abdominis, and possibly other abdominal muscles remained disadvantaged biomechanically into the eighth post-birth week.

In summary, the functional capabilities of the abdominal muscles in producing anterior pelvic stabilisation and trunk extension, flexion and rotation against a resistance, has been shown to be altered from approximately 26 weeks gestation and to remain altered up to eight weeks post-birth. As the pregnancy progressed the functional changes paralleled, in time, the structural changes seen in Rectus Abdominis. Post-birth, continued functional deficits indicate the abdominal muscles remained disadvantaged biomechanically.

CHAPTER 8:

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

On the basis of the results of the present study the following conclusions may be drawn for: -

A. Abdominal Muscle Structure and Function During Pregnancy and the Immediate Post-birth Period

1. The gross structure of the Rectus Abdominis was altered as pregnancy progressed. The separation between the Recti above, below and at umbilicus, and the superior and inferior angles of insertion in the sagittal and coronal planes were significantly ($p < 0.05$) altered by 30 weeks gestation. Further significant changes ($p < 0.05$) were seen in Recti separation above and at umbilicus, and all angles of insertion as pregnancy progressed to 38 weeks gestation. There was a significant ($p < 0.05$) increase in Rectus Abdominis medial edge length between weeks 14 and 38 gestation. Post-birth four weeks there was significant ($p < 0.05$) reversal in Recti separation;
2. Given the limitations of the present study, the increase in Rectus Abdominis muscle length found would be unlikely to significantly reduce the tension produced by the muscle. However, the altered angles of insertion would change the line of action of the Rectus Abdominis,

therefore reducing the moment arm length and as a consequence the torque production of the muscle. Therefore Rectus Abdominis functional deficits during pregnancy may be more related to reduced torque production rather than reduced tension generation;

3. The abdominal muscles' ability to stabilise the pelvis was similar in maternal subjects at weeks 14 to 18 gestation to non-pregnant subjects, although this ability had decreased in some subjects by 26 weeks gestation. All maternal subjects had decreased capability to stabilise the pelvis during late pregnancy and up to eight weeks post-birth;

4. A trend was seen for a reduction in IEMG signal level in External Oblique as pregnancy progressed, with a subsequent increase post-birth. This was not thought to be due to increased subcutaneous adipose tissue or altered background noise;

5. Abdominal muscle inter-relationship, as measured by rel-IEMG, was altered in late pregnancy relative to early pregnancy. This may reflect variations in the movement performed due to the obstruction to approximation of the anterior thoracic cage to the pelvis by the gravid uterus, rather than a muscle functional deficit.

B. Abdominal Muscle Test Validation

1. The pattern of muscle usage indicated that the primary muscle used in the test was the Rectus Abdominis;
2. For Levels 1 to 3 the EMG output of all abdominal muscles tested tended to increase with the level of test difficulty, the greatest increment being seen between Levels 2 and 3;
3. Level 4 used a different pattern of abdominal muscle synergy in relation to Levels 1 to 3 and therefore it may not be valid as part of this muscle test.

RECOMMENDATIONS

The results of this study have indicated the following recommendations for :-

A. Abdominal Exercises During Pregnancy and up to Eight Weeks Post-birth

1. Abdominal exercises should be performed with caution after 30 weeks gestation through to eight weeks post-birth, due to the abdominal muscles reduced ability to stabilise the pelvis, and potentially reduced torque production;
2. During late pregnancy, head-raising exercises perhaps are as effective in inducing abdominal muscle activity as attempting to perform curl-up type exercises;

B. Abdominal Muscle Test

Level 4 should be redesigned to be similar in it's pattern of muscle use, to Levels 1 to 3

C. Further Study

The results of this study have highlighted several factors that it would be interesting to investigate in the future: -

1. Examination of the human Rectus Abdominis response to increased functional workloads during pregnancy.
2. The effect of the hormone relaxin on skeletal muscle and connective tissue in humans.
3. The effect of hormones, such as progesterone, on skeletal muscle.
4. Human skeletal muscle and connective tissue response to long term stretch.
5. Investigate the effect of abdominal exercise during pregnancy on Recti separation.
6. Investigate the minimum change in angles of insertion at which reduced torque production for Rectus Abdominis will have a demonstrable affect on the functional capacity of Rectus Abdominis.

7. Investigate the effect of posture during pregnancy on the ability of the abdominal muscles to posteriorly tilt the pelvis.

CHAPTER 9:

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APPENDIX I

Consent form and Participant Information for the Maternal Subjects

Analysis of the Structural and Functional Changes
to the Abdominal Wall During Pregnancy

This project forms part of the requirements for a Honors Master of Science Thesis in the Department of Human Movement, University of Wollongong.

Consent form

Subject

I _____ have read the participant information and consent to participate as a subject in the project. I am aware that I may withdraw from the study at any time during this project.

Signature _____

Date _____

Consulting Obstetrician/Physician

I _____ have read the participant information and give my permission for _____ to participate in the project. I am aware that I may withdraw my consent for the subject's participation at any time during this project.

Signature _____

Date _____

Analysis of the Structural and Functional Changes
to the Abdominal Wall During Pregnancy

This project forms part of the requirements for a Honors Master of Science Thesis in Department of Human Movement, University of Wollongong.

Participant Information

Each four weeks you will participate in the following:-

1. Height measurement
2. Weight measured
3. Give estimated pregnancy duration in weeks
4. Pelvis stabilising test.
 - A. You will be supine
 - B. A child's sphygmomanometer inflated to 10 mm Hg will be placed under the small of the back
 - C. You will be instructed to flatten the small of your back. The pressure will be recorded as you begin to flatten the lumbar curve
 - D. You must maintain the above recording during the following exercises. The test will cease when the minimum pressure reading recorded above is no longer maintained during the exercise.
 - i) Right leg bent, foot on plinth. Straighten left leg horizontally. Repeat for the right leg.
 - ii) Right leg bent (to 90^0 of hip flexion), held by hands. Straighten left leg horizontally. Repeat for the right leg.
 - iii) Right leg bent (to 90^0 of hip flexion), supported by muscles only. Straighten left leg horizontally. Repeat for the right leg.
 - iv) Repeat iii) lowering both limbs simultaneously

The test was developed by A Hunt and E Henley from the Cumberland College of Health Sciences Physiotherapy School.

5. You will be photographed, supine, with a reference structure positioned over your abdomen (facial features will be blacked out). Water soluble marker pens will be used to mark the following points;

- i) pubic bone (Pubic hair over the mons pubis will be gelled down and white tape used as a marker)
- ii) sternum
- iii) midline abdomen

6. You will be supine with your knees bent, feet flat on the plinth.

- i) An Electromyographic (EMG) recording to establish background electrical activity (foetal and maternal) will be taken while you are resting.
- ii) You will be instructed to tighten your abdominal muscles as hard as possible. EMG will be recorded.
- iii) EMG will be recorded during the exercises specified below. Five trials of each exercise will be done and rest periods will be given between trials.

Exercises i-iii will be done while you are supine, with your knees bent and feet flat on the plinth. You will be instructed to breathe out gently as each exercise is performed.

i) Pelvic Tilt

Gently but firmly, tilt the pelvis so that the small of the back is flattened. There should be no pressure through the feet.

ii) Right hand to left knee

With the left hand on the abdomen, lifting the head and shoulders reach forward towards the left knee with the right hand. Hold for a count of "1 elephant" then relax.

iii) Head and shoulder raise

With both hands on the abdomen, curl head gently towards the shoulders, then lift the head and shoulders. Hold for a count of "1 elephant" then relax.

iv) Straight Sit Back

Sitting upright, knees bent, feet apart and on the plinth. Stretch your arms out in front and roll backwards a little way. Breathe out as you execute the movement. Hold for the count of "1 elephant" then return to the upright position.

Between each exercise you will be instructed to move your knees towards your abdomen, roll to your side and rest with your upper knee supported by a pillow.

The exercises are given as part of an pregnancy exercise programme, which is advised by two Sydney Obstetric Physiotherapists (J Simons and J Sundin) done at home and during supervised classwork.

7. Skin fold thickness measurements will be taken near the right hip and the umbilicus

8. Direct measurement of the length of Rectus Abdominis using a tape measure.

YOU MAY WITHDRAW FROM PARTICIPATION IN THIS PROJECT AT ANY TIME

APPENDIX II

Consent Form and Participant Information for Control Subjects

Analysis of the Structural' and Functional Changes
to the Abdominal Wall During Pregnancy

This project forms part of the requirements for a Honors Master of Science Thesis in the Department of Human Movement, University of Wollongong.

Consent form

I _____ have read the participant information and consent to participate as a subject in the project. I am aware that I may withdraw from the study at any time during this project.

Signature _____

Date _____

Participant Information

Each four weeks you will participate in the following ;-

1. Height measurement

2. Weight measurement

3. EMG recording from the upper and lower Rectus abdominis and External Oblique. the electrode site will be prepared by shaving, wiping with alcohol and abrading with emery paper.

You will be supine with your knees bent, feet flat on the plinth.

Recording s will be taken for;

i) background electrical activity, 2 trials

ii) Maximum isometric contraction, 3 trials

iii) Pelvic tilt, Curl-Up, Diagonal curl-up, straight sit back, 5 trials each with rest periods between

7. Skins folds will be taken at each electrode site

YOU MAY WITHDRAW FROM PARTICIPATION IN THIS PROJECT AT ANY TIME

APPENDIX III

Abdominal Exercises

The abdominal exercises used in the study were primarily selected from those recommended by physical therapists for use during pregnancy and the post-birth period as detailed in Chapter 2. In addition, some abdominal exercises were included as they are commonly used in general exercise classes attended by pregnant women. All exercises were performed slowly and smoothly to the verbal directions of the author. The selected abdominal exercises were Pelvic Tilt, Curl-up, Diagonal Curl-up and Seated Tilt-back. The details of these exercises are as follows: -

Pelvic Tilt:

The subject was supine with her knees flexed and feet flat on the plinth. She was instructed to posteriorly tilt her pelvis by firmly pressing the lumbar spine into the plinth using her abdominal muscles and no pressure on the feet. She then held the position for a given time then relaxed. The verbal instructions given were, "Flatten the lower back, hold for 'one elephant', and relax".

Curl-up:

The subject was supine with her knees flexed and feet flat on the plinth. She was instructed to flatten her lower back. The subject then slowly curled her head and trunk up, reaching her hands towards her knees, to a maximum of 45° of trunk flexion as estimated by the author. The subject held the position for a given time, then gently uncurled, lowered herself to the plinth and relaxed. The verbal instructions given were, "Flatten the lower back, curl-up, hold for 'one elephant', lower, and relax".

Diagonal Curl-up:

The subject was supine with her knees flexed and feet flat on the plinth. She was instructed to flatten her lower back. The subject then slowly curled her head and trunk up, reaching her right hand across the trunk towards her left knee, to a maximum of 45^0 of trunk flexion as estimated by the author. The subject held the position for a given time, then gently uncurled, lowered herself to the plinth and relaxed. The verbal instructions given were, "Flatten the lower back, curl-up, hold for 'one elephant', lower, and relax".

Seated Tilt-back:

The subject was seated on the plinth, arms reaching forward at shoulder height, knees flexed and feet, shoulder width apart, flat on the plinth. She was instructed to round her lower back, tilt back to a maximum of 45^0 of trunk extension as estimated by the author and hold the position for a given time. Then, to lift anteriorly to the starting position. The verbal instructions given were, "Round the lower back, tilt back, hold for 'one elephant', lift, and relax".

APPENDIX IV

Subject Profiles

At each test session general information for both control and maternal subjects was recorded. The data collected was summarised as follows: -

Control Group

There were ten nullipara female subjects in the control group. They were university student volunteers, aged 18 to 32 years, with a mean of 21.6 years. The control subject's weight ranged between 51.8 to 73.5 kg with a mean of 60.8 kg, and their height range was between 156.7 to 175.8 cm with a mean of 163.9 cm.

Maternal Group

The maternal subjects were six primigravids, with a single foetus, who volunteered for the study. Table IVa presents the maternal subject profile data. The maternal subjects were aged 28 to 33 years, with a mean age of 29.2 years. Their height ranged from between 156.5 to 174 cm, with a mean of 164.6 cm. The majority of subjects commenced the study at 18 weeks or less gestation, before there was any visible external evidence of the pregnancy at the surface of the abdomen. However, one subject commenced the study at 22 weeks gestation. Length of gestation ranged from 36 to 42 weeks with a mean of 39 weeks and neonate weight ranged from 2.200 to 3.337 kg, with a mean of 2.796 kg.

Due to withdrawal on medical grounds and pre-term deliveries, one subject by week 34 and two more subjects by week 38, temporarily withdrew from the study. All subjects participated in post-birth test sessions.

Table IVa. Maternal Group Subject Profile Data

Subject	1	2	3	4	5	6
Age (years)	28	28	28	33	28	30
Height (cm)	167.0	162.4	166.6	161.3	156.5	174.0
Gestation at 1st test (weeks)	15	18	13	14	22	13
Initial Weight (kg)	61.0	65.7	67.5	60.4	54.0	60.1
Post-birth Weight (kg) _a	59.6	64.6	65.5	59.4	53.0	61.5
Gestation total (weeks)	36	36	40	40	42	40
Neonatal Weight (kg)	2.200	2.590	2.660	2.680	3.337	3.314

_a Week 8 post-birth

Exercise History

For the maternal subjects at each test session the average number and type of exercise sessions the subject had participated in, for the previous four weeks, were recorded. An exercise session was included if the duration was 30 minutes or greater, but an assessment of the intensity of exercise was not possible. Table IVb shows, for the maternal subjects, the number of exercise sessions per week over the study period. The majority of maternal subjects exercised three times or more per week between week 14 to week 38 gestation.

Table IVb. Maternal Group Exercise History

	Average Number of Exercise Sessions per Week					
Subject Gestation (weeks)	1	2	3	4	5	6
14	3 +		2	3 +		3 +
18	3 +	3 +	3 +	3 +		3 +
22	3 +	2	1	3 +	3 +	3 +
26	3 +	2	1	3 +	3 +	3 +
30	2	3 +	2	3 +	3 +	3 +
34	*	3 +	1	2	3 +	3 +
38	*	*	*	1	3 +	3 +
Post-birth (weeks)						
4	0	3 +	0	0	1	3 +
8	0	3 +	0	1	1	3 +

3 + denotes three or more exercise session per week
 * denotes missing data due to withdrawal on medical ground or pre-term delivery

Post-birth, the number of exercise sessions per week decreased, with most subjects exercising once a week or less. The type of exercise session recorded included brisk walking, cycling, windsurfing, aerobic classes, weights, and swimming. However, the number of subjects participating each type of exercise was too low to statistically analyse the effect of different types of exercise on pregnancy.

Discussion

A normal pregnancy term is between 38 to 42 weeks gestation (Clapp & Dickstein 1984), and 4/6 of this study's maternal subjects were delivered at term. Previous studies on women who exercised during pregnancy, have reported mean lengths of gestation ranging from 39.1 to 40.75 weeks (Clapp & Dickstein 1984, Hall & Kaufmann 1987, Jarrett & Spellacy 1983, Wong & McKenzie 1987). The

mean length of gestation for this study's maternal subjects was slightly lower at 39 weeks.

The mean neonate weight for this study was 2.796 kg. This was below the range of mean birth weights for previous studies on women exercising during pregnancy. Previous studies report a mean birth weight ranging from 3.009 to 3.733 kg (Clapp & Dickstein 1984, Hall & Kaufmann 1987, Jarrett & Spellacy 1983, Wong & McKenzie 1987).

In summary, the maternal subjects for this study were active throughout their pregnancies but, post-birth, the number of exercise sessions per week was reduced. The mean length of gestation and mean neonate weight from this study, were below the ranges reported by previous studies.

APPENDIX V

Consent Form and Participant Information for Muscle Test Validation Subjects

Quantification of a Muscle Test:
Abdominal Muscle Strength

This project forms part of the requirements for a Honors Master of Science Thesis in the Department of Human Movement, University of Wollongong.

Consent Form

I _____ have read the participant information and consent to participate as a subject in the project. I am aware I may withdraw from the study at any time.

Medical Information:

Have you ever had a back injury ? Yes/No

If yes, Type of injury:

Have you ever had an abdominal muscle injury ? Yes/No

If yes, Type of injury:

Signature _____

Date _____

Quantification of a Manual Muscle Test:

Abdominal Muscle Strength

This project forms part of the requirements for a Honors Master of Science Thesis in the Department of Human Movement, University of Wollongong.

Participant Information

The subject will participate in the following:

1. Height and weight measurement
2. Exercise history
3. Age
4. Attachment of electrodes to the abdomen at the following sites:
 - i) Upper Rectus Abdominus - midway between the umbilicus and the sternum
 - ii) Lower Rectus Abdominus - midway between the umbilicus and the pubis
 - iii) External Oblique - 5cm above the right Anterior Superior Iliac Spine (ASIS)
 - iv) Internal Oblique and Transversus Abdominus - mid triangle bounded by ASIS, lateral edge of Rectus Abdominus and the inguinal ligament
5. 2 trials of Maximum Voluntary Isometric Contraction (MVIC)

6. Pelvis Stabilising test

The test is as follows.

- A. Subject is supine knees flexed and feet flat on the surface. A child's sphygmomanometer cuff, inflated to 10 mm Hg, is placed under the lower back, the inferior edge level with the iliac crests.
- B. The subject flexes the knees towards the chest one at a time, and while supporting the thighs with the hands, with the hips at 90 degrees, actively flattens the lumbar spine (the buttocks should not lift off the surface).

Record the pressure as the lumbar spine begins to flatten.

The subject must maintain the above recording within 10mm Hg for each test. The test will cease when the minimum pressure reading recorded above is not able to be maintained during the test.

Score 1: In crook lying - knees at 90^0 , measure and record the distance between the ischial tuberosities and the heel

the subject can flatten lower back and extend either lower limb, just off the surface.

Score 2: 90^0 of hip flexion thighs held.

the subject can flatten lower back and extend either lower limb, just off the surface.

Score 3: 90^0 of hip flexion no thigh support.

the subject can flatten lower back and extend either lower limb, just off the surface.

Score 4: 90^0 of hip flexion no thigh support.

the subject can flatten lower back and extend both lower limbs, just off the surface.

The last successfully completed task is considered to be the level of ability of the abdominal muscles. Five trials will be conducted at each level with rest periods between each trial.